AD-A065 147   ARMY MOBILITY EQUIPMENT RESEARCH AND DEVELOPMENT COMM--ETC F/G 13/6
BASELINE TESTS OF THE ELECTRA-VAN MULTIPURPOSE ELECTRIC VAN.(U)
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BASELINE TESTS OF THE ELECTRA-VAN MULTIPURPOSE ELECTRIC VAN

by

Edward J. Dowgiallo, Jr.
Cornelius E. Bailey, Jr.
Ivan R. Snellings
and
William H. Blake

November 1978

MERADCOM

U.S. ARMY MOBILITY EQUIPMENT
RESEARCH AND DEVELOPMENT COMMAND
FORT BELVOIR, VIRGINIA

A056 727

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
2260

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
(6) BASELINE TESTS OF THE ELECTRA-VAN MULTIPURPOSE ELECTRIC VAN,

5. TYPE OF REPORT & PERIOD COVERED
(9) Test Report,
~~19 Jul - 17 Aug 77~~

6. PERFORMING ORG. REPORT NUMBER
CONS/0421-3

7. AUTHOR(s)
(10) Edward J. Dowgiallo, Jr., Cornelius E. Bailey, Jr., Ivan R. Snellings ~~and~~ William H. Blake

8. CONTRACT OR GRANT NUMBER(s)
Interagency Agreement
(15) EC-77-A-31-1042

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Electrochem Div., Elec Pwr Lab; U.S. Army Mobility Equipment Research and Development Command; Fort Belvoir, Virginia 22060

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
U.S. Army Mobility Equipment Research and Development Command; Fort Belvoir, VA 22060

12. REPORT DATE
(11) November 1978

13. NUMBER OF PAGES
72

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
Electric & Hybrid Highway Vehicle Systems Program
Division of Transportation Energy Conservation, Department of Energy; Washington, D.C.

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

(12) 71 p.

(14) MERADCOM-2260

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

(18) DOE (19) CONS/0421-3

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Electric Vehicle
Traction Battery

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Electra-Van, Model 500-108, an electric, quarter-ton, multipurpose van, was tested at the US Army Aberdeen Proving Ground Test Facilities in Aberdeen, Maryland, as part of a Department of Energy (DOE) project to characterize the state-of-the-art of electric vehicles. The Electra-Van is manufactured in Austin, Texas, by Jet Industries, Inc. It is a converted Subaru minivan. It is powered by eighteen, 6-volt batteries that are connected to the motor through an SCR controller actuated by a foot pedal to control motor

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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speed. The 14.2-horsepower motor drives the rear wheels through a four-speed manual transmission. No regenerative braking is provided.

PREFACE

The Electric and Hybrid Vehicle Program was conducted by the U.S. Army Mobility Equipment Research and Development Command (MERADCOM) under the guidance of the former Energy Research and Development Administration (ERDA) which is now part of the Department of Energy (DOE). Many beneficial suggestions, computer programming, and data tabulations were made by Scientific and Engineering Application Staff Group members David Scott and Arthur Nickless.

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BASELINE TESTS OF THE ELECTRA–VAN MULTIPURPOSE ELECTRIC VAN

I. SUMMARY

The Electra-Van, a multipurpose electric vehicle manufactured in Austin, Texas, by Jet Industries, Incorporated, was tested at the US Army Aberdeen Proving Ground test facilities in Aberdeen, Maryland, between 19 July and 17 August 1977. The tests are part of a Department of Energy (DOE) project to characterize the state-of-the-art of electric vehicles. This report presents the performance of the Electra-Van.

The Electra-Van, Model 500-108, is a four-passenger delivery truck with a reinforced steel body and is powered by eighteen, 6-volt batteries. The batteries are connected to a 14.2-horsepower motor through a silicon-controlled-rectifier (SCR) controller actuated by a foot pedal to control motor speed. The motor drives the rear wheels through a four-speed manual transmission. No regenerative braking is provided on this vehicle.

The results of the tests are summarized in Table 1.

Table 1. Test Results

Test Speed of Driving Cycle	Type of Test: Range (km)	Range (mi)	Road Load Power (kW)	Road Energy (MJ/km)	Road Energy (kWh/mi)	Energy Consumption (MJ/km)	Energy Consumption (kWh/mi)
40 km/h (25 mi/h)	120.8	75.1	4.3	0.30	0.13	0.94	0.48
56 km/h (35 mi/h)	99.9	62.1	8.0	0.37	0.17	0.99	0.44
Schedule B	103.2	64.1	–	–	–	0.97	0.43
Schedule C	89.2	55.4	–	–	–	1.09	0.49

Acceleration: 0 to 32 km/h (20 mi/h) in 10 seconds.
0 to 48 km/h (30 mi/h) in 17 seconds.

All tests were run at the gross vehicle weight of 1476 kilograms (3250 lbm). The Electra-Van accelerated from 0 to 48.3 kilometers per hour (0 to 30 mi/h) in 17 seconds.

II. INTRODUCTION

The vehicle tests and the data presented in this report are in support of Public Law 94-413 enacted by Congress on September 17, 1976. The Law requires the Energy Research and Development Administration (ERDA), now DOE, to develop data characterizing the state-of-the-art of electric and hybrid vehicles. The data so developed are to serve as a baseline to compare improvements in electric and hybrid vehicle technologies, to assist in establishing performance standards for electric and hybrid vehicles, and to help guide future research and development activities.

The US Army Mobility Equipment Research and Development Command (MERADCOM) under the direction of the Electric and Hybrid Research, Development, and Demonstration Office of the Division of Transportation Energy Conservation, DOE, has conducted track tests of electric vehicles to measure their performance characteristics and vehicle component efficiencies.

The tests were conducted according to DOE Electric and Hybrid Vehicle Test and Evaluation Procedures described in Appendix E of MERADCOM Report 2244.[1]

The assistance and cooperation of Jet Industries, Incorporated, are greatly appreciated. The Department of Energy provided funding support and guidance during this project.

US customary units were used in the collection and reduction of data. The units were converted to the International System of Units (Systeme International), or SI, for presentation in this report (Table 2). US customary units are presented in parentheses.

III. OBJECTIVES

The characteristics of interest for the Electra-Van are vehicle speed, range at constant speed, range over stop-and-go driving schedules, maximum acceleration, gradeability, road energy consumption, road power, indicated energy consumption, and battery characteristics.

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[1] E. J. Dowgiallo, Jr.; C. E. Bailey, Jr.; I. R. Snellings; and W. H. Blake; "Baseline Tests of the EVA Metro Electric Passenger Vehicle," MERADCOM Report 2244 (July 1978).

Table 2. Parameters, Symbols, Units, and Unit Abbreviations

Parameter	Symbol	SI Units Unit	SI Units Abbreviation	U.S. Customary Units Unit	U.S. Customary Units Abbreviation
Acceleration	a	meter per second squared	m/s^2	mile per hour per second	mi/h/s
Area	–	square meter	m^2	square foot; square inch	ft^2; $in.^2$
Energy	–	megajoule	MJ	kilowatt hour	kWh
Energy Consumption	E	megajoule per kilometer	MJ/km	kilowatt hour per mile	kWh/mi
Energy Economy	–	megajoule per kilometer	MJ/km	kilowatt hour per mile	kWh/mi
Force	F	newton	N	pound force	lbf
Integrated current	–	ampere hour	Ah	ampere hour	Ah
Length	–	meter	m	inch; foot; mile	in.; ft; mi
Mass; weight	w	kilogram	kg	pound mass	lbm
Power	P	kilowatt	kW	horsepower	hp
Pressure	–	kilopascal	kPa	pound force per square inch	lbf/in^2
Range	–	kilometer	km	mile	mi
Specific energy	–	megajoule per kilogram	MJ/kg	watt hour per pound mass	Wh/lbm
Specific power	–	kilowatt per kilogram	kW/kg	kilowatt per pound mass	kW/lbm
Speed	V	kilometer per hour	km/h	mile per hour	mi/h
Volume	–	cubic meter	m^3	cubic inch; cubic foot	$in.^3$; ft^3

IV. TEST VEHICLE

1. **Description.** The Electra-Van, an electric delivery truck, Model 500-108, is a converted Subaru minivan in the 500-pound payload class. The compact vehicle has "bench" type seating in front for a driver and one passenger. There is seating space in the rear over the battery box for two additional passengers or the rear seat back can be removed to utilize the full load space for cargo. The Electra-Van is manufactured by Jet Industries, Incorporated, Austin, Texas. The vehicle is powered by eighteen 6-volt batteries located in a battery box in the cargo area. The batteries are connected to the series motor through an SCR Cableform controller operated from a foot pedal. The motor is connected via a clutch to a four-speed manual transmission.

The battery, the SCR controller, and a 10.6-kilowatt d.c. motor are connected in series. The vehicle is shown in Figure 1 and described in detail in Appendix A. A single-phase, 220-volt, off-board battery charger is used to charge the traction batteries. No regenerative braking is provided on this vehicle.

2. **Operating Characteristics.** A key switch is used to close the main switch enabling an SCR Cableform controller, which is actuated by a foot throttle, to change the voltage applied to the 10.6-kW motor. A four-speed manual transmission is provided for forward and reverse directions.

V. INSTRUMENTATION

The Electra-Van was instrumented to measure vehicle speed and range, battery voltage, current, "instantaneous" power, and averaged power. The battery charger input in a.c. kilowatt-hours and output in d.c. amperes were also measured. Battery electrolyte temperatures were measured with thermometers. A brief description of the instrumentation system follows.

Instrumentation consisted of signal-conditioning circuits and a magnetic tape recorder for recording analog signals of electrical parameters. Details on the recorder are given in Appendix B of MERADCOM Report 2244.[2] The recorder was operated in the frequency modulation mode at 4.763 cm (1.875 in.) per second. The signal-conditioning circuitry to the recorder consisted of a main battery-voltage divider, a shunt-voltage amplifier for current monitor, an analog multiplier, and averager circuits averaging power and current since the recorder response was less than 0.3 dB down at 500 hertz. A voltage proportional to battery power was produced by the instantaneous multiplication of voltages proportional to battery voltage and current. Voltages

2 **E. J. Dowgiallo, Jr.; C. E. Bailey, Jr.; I. R. Snellings; and W. H. Blake; "Baseline Tests of the EVA Metro Electric Passenger Vehicle," MERADCOM Report 2244 (July 1978).**

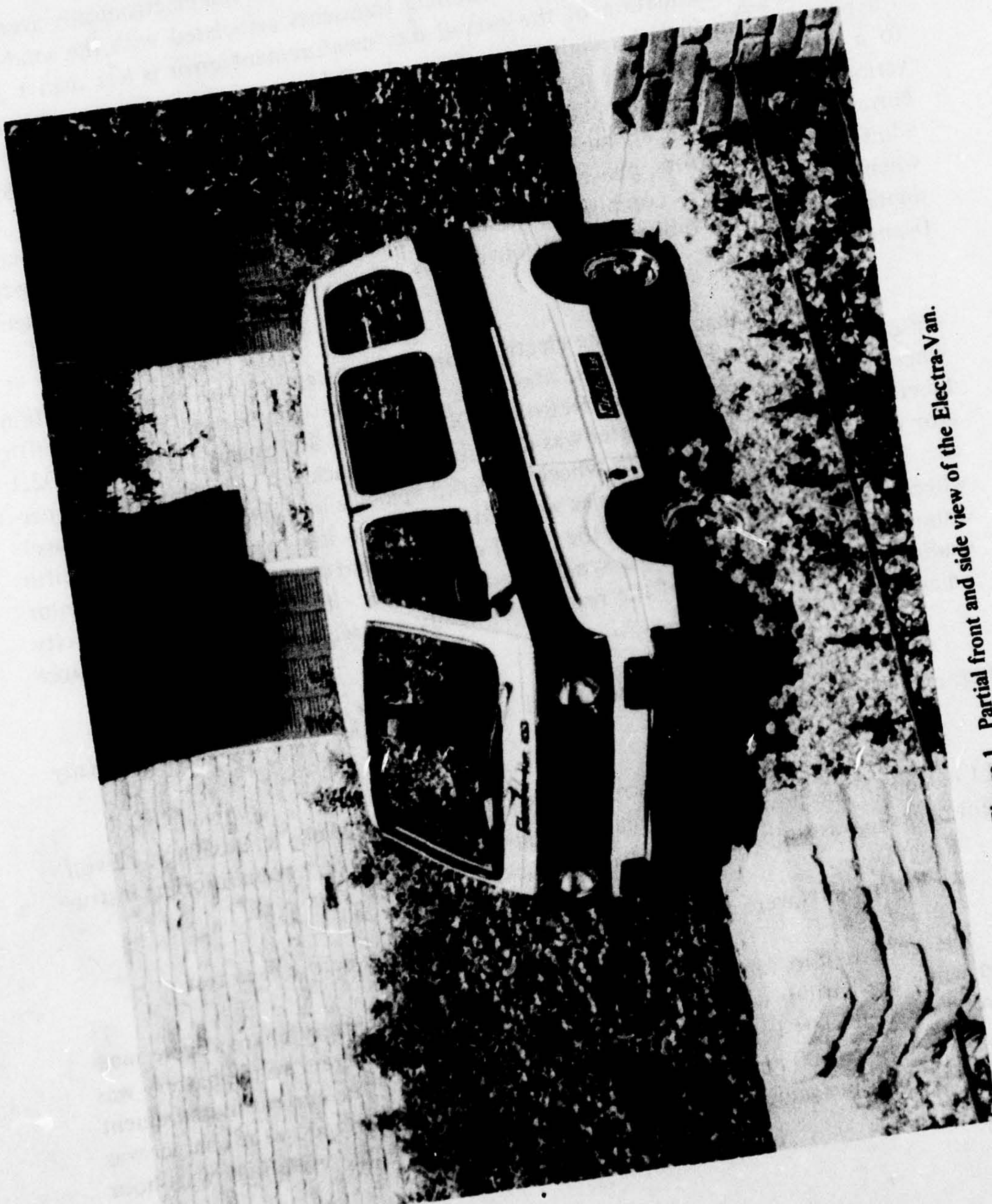

Figure 1. Partial front and side view of the Electra-Van.

proportional to current and power were both recorded raw and electronically averaged. The raw values include the rapid switching transients associated with the solid-state controller. An estimation of the overall d.c. measurement error is less than ± 1.8% for power. This includes digitization from the field-recorded, analog magnetic tape to a computer-compatible, digitized magnetic tape. The measurement error of the various conditioning circuits can be broken down as follows: current shunt (± 0.25%), current amplifier (± 1%), multiplier (± 0.25%), magnetic tape recorder (± 1%). In addition to these errors, phase deterioration starts to be significant above 3 kilohertz when the multiplier is combined with an averager (± 1%); and, finally, the analog-to-digital converter at 16 bits and 100 conversions per second did not introduce any significant error.

A schematic diagram of the electric-propulsion system with the instrumentation sensors is shown in Figure 2. A Laboratory Equipment Corporation Tracktest Fifth Wheel with the Model DD1.1 Electronics Digital Speed Meter and the Model DD2.1 Electronic Digital Distance Meter was used during the track tests. A tachometer generator was connected to the fifth wheel to record velocity and calculate distance traveled. The fifth wheel and auxiliaries weighed about 18.6 kilograms (41 lb). The fifth wheel was calibrated by rotating the wheel on a constant-speed, fifth-wheel calibrator drum mounted on the shaft of a synchronous a.c. motor. The accuracy of the velocity readings was within ± ½% of the reading. Velocity was recorded on a Lockheed Store 7 magnetic tape recorder.

Battery electrolyte temperatures and specific gravities were measured manually before and after the tests.

Power for the fifth-wheel instruments was provided by a vehicle, auxiliary, 12-volt SLI battery. The power for the magnetic tape recorder and signal conditioning instrument package was supplied from a battery pack.

All instruments were calibrated periodically with checks before each test.

The current into the battery and the energy into the battery charger were measured while the battery was recharged after each test. The current to the battery was recorded on a Hewlett Packard 7100 B strip chart recorder. The current measurement used a 100 ampere-100 milivolt current shunt. The energy delivered to the charger was measured with a Sangamo Electric Type J4S 30TA, single-phase, residential, watt-hour meter.

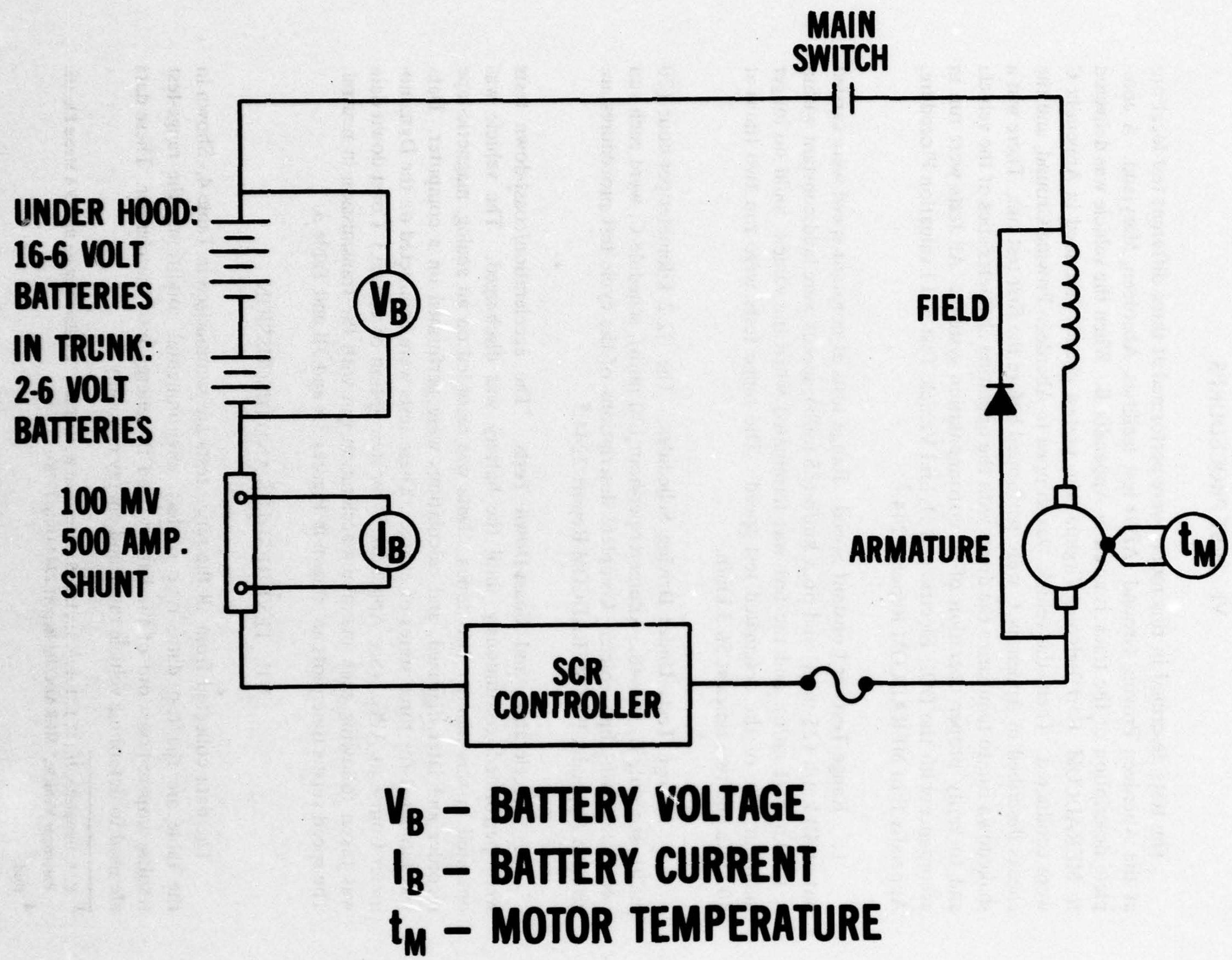

Figure 2. Schematic diagram of vehicle electric propulsion system showing instrumentation monitors.

VI. TEST PROCEDURES

The tests described in this report were performed at three different test locations at the Aberdeen Proving Ground (APG) test facilities, Aberdeen, Maryland. A complete description of the track is given in Appendix B. When the vehicle was delivered to MERADCOM, Fort Belvoir, Virginia, the pretest checks described in Appendix C were conducted. Then, the vehicle was shipped to Aberdeen Proving Ground, and the checks described in Appendix C were performed before the first test run. There was a shakedown run to familiarize the driver with the operating characteristics of the vehicle and to verify proper operation of all instrumentation systems. All tests were run in accordance with the DOE Electric and Hybrid Vehicle Test and Evaluation Procedure, Appendix E of MERADCOM Report 2244.[3]

1. **Range Tests at Constant Speed.** Range tests at constant speed were carried out at 40 km/h (25 mi/h) and 56.3 km/h (35 mi/h); speeds were held constant within ± 1.6 km/h (1 mi/h), and the test was terminated when the vehicle could no longer maintain 95% of the designated test speed. The range tests were run two times at 40 km/h and two times at 56.3 km/h.

2. **Range Tests Under Driving Schedules.** The 32.2 kilometer-per-hour (20 mi/h), schedule B, and 48.3 kilometer-per-hour (30 mi/h), schedule C, were each run two times with this vehicle. Complete descriptions of the cycle test procedures are given in Appendix E of MERADCOM Report 2244.[4]

3. **Acceleration and Coast-Down Tests.** The acceleration/coast-down tests were performed continuously until the battery was discharged. The vehicle was operated in this manner two times. Data was recorded on an analog, magnetic-tape recorder and later digitized, and calculations were performed on a computer. Data was tabulated for three states of charge. These tests were conducted on the Dynamometer Course at APG. (See Appendix B for description of course.) Coast-down data was taken following each maximum-accleration run with the transmission in neutral. The speed versus time plots are shown in Figures 3A and 3B and Table 3.

VII. TEST RESULTS AND DISCUSSION

The data collected from all the range tests are summarized in Table 4. Shown in the table are the test data, type of test, environmental conditions, the range-test results, ampere-hours out of the battery, and the energy into the charger. These data are used to determine vehicle range and energy economy.

[3] E. J. Dowgiallo, Jr.; C. E. Bailey, Jr.; L. R. Snellings; and W. H. Blake; "Baseline Test on the EVA Metro Electric Passenger Vehicle," MERADCOM Report 2244 (July 1978).

[4] Ibid.

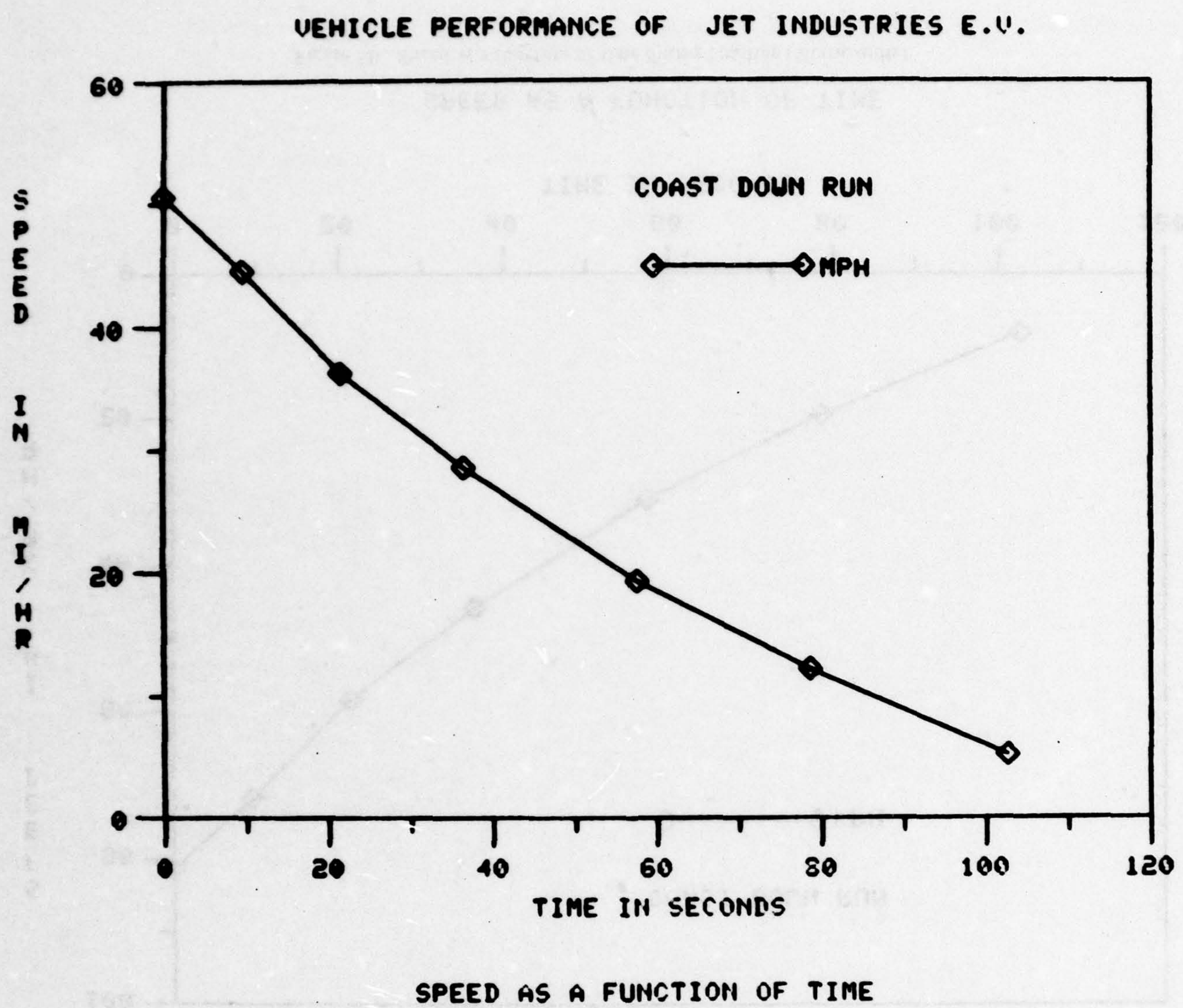

Figure 3A. Speed as a function of time during coasting (English units).

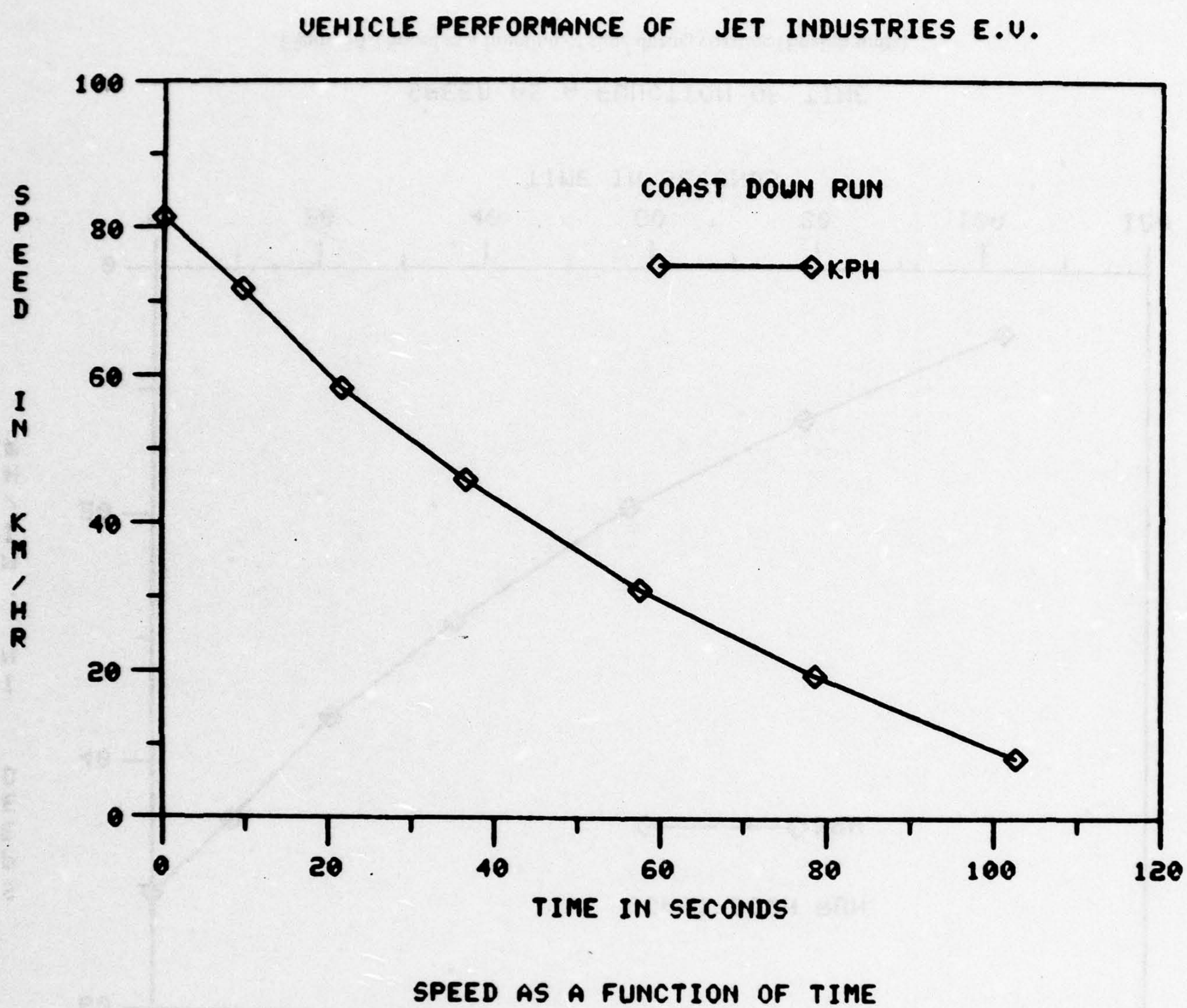

Figure 3B. Speed as a function of time during coasting (Metric units).

Table 3. Speed Versus Time During Coasting

Time (s)	Vehicle Speed (km/h)	(mi/h)
0	81.3	50.5
9.6	71.6	44.5
21.6	58.2	36.2
36.6	45.8	28.5
57.6	31.1	19.3
78.6	19.6	12.2
102.6	8.3	5.2

1. **Maximum Speed.** The maximum speed of the vehicle was measured during the acceleration tests. The measured maximum speed was 83.7 km/h (52 mi/h) for this vehicle. Note that this differs from the top speed used in the range test which was limited to 35 mi/h at the request of Jet Industries.

2. **Maximum Acceleration.** The maximum acceleration of the vehicle was measured with the batteries fully charged, 40% discharged, and 80% discharged. The results of the tests are shown in the curves of Figures 4A and 4B and are tabulated in Table 5. The average acceleration, $\bar{a}_n$, *was calculated for the time period,* t_{n-1} *to* t_n, where the vehicle speed increased from V_{n-1} to V_n from the equation,

$$\bar{a}_n = \frac{V_n - V_{n-1}}{t_n - t_{n-1}},$$

and the average speed of the vehicle, $\overline{V}$, was calculated from the equation,

$$\overline{V} = \frac{V_n + V_{n-1}}{2}$$

Average acceleration as a function of speed is shown in Figures 5A and 5B and Table 6. In the acceleration curves shown in Figures 5A and 5B, at speeds below about 19 km/h (12 mi/h), the acceleration magnitudes increase with increasing battery percent of discharge. This may be due to the effect on driver selection of the time to shift gears caused by the effects of temperature increases on tire rolling resistance, lubricants, battery, etc. These tests were run consecutively, and the percent of discharge was determined by computer calculation. Discharging the battery by continuous start-stop vehicle operation rather than allowing a cool off period while the battery was discharged to each state of charge was considered more realistic.

Table 4. Summary of Test Results for Electra-Van

(a) SI Units

Test Date	Test Condition (Constant Speed: (km/h; or Driving Schedule)	Wind Velocity (km/h)	Temperature (C°)	Range (km)	Number of Cycles	Energy into Charger (MJ)	Indicated Energy Consumption (MJ/km)
7-27-77	40	3.2	15.5	114.2	–	95.4	1.14
7-28-77	40	4.8	21.6	127.4	–	100.8	1.01
7-29-77	56	4.8	18.9	98.2	–	126.0	1.01
8-02-77	B	8.0	20.5	100.2	292	124.2	1.01
8-04-77	C	Calm	20.0	91.4	146	98.3	1.03
8-05-77	56	Calm	20.5	101.6	–	138.2	0.96
8-09-77	C	4.8	30.0	86.9	151	89.3	1.14
8-15-77	B	12.9	26.0	106.1	303	97.2	0.92

(b) U.S. Customary Units

Test Date	Test Condition (Constant Speed: mi/h; or Driving Schedule)	Wind Velocity (mi/h)	Temperature (°F)	Range (mi)	Number of Cycles	Energy into Charger (kWh)	Indicated Energy Consumption (kWh/mi)
7-27-77	25	2	60	71.0	–	26.5	0.51
7-28-77	25	3	71	79.2	–	28.0	0.45
7-29-77	35	3	66	61.0	–	35.0	0.45
8-02-77	B	5	69	62.3	292	34.5	0.45
8-04-77	C	Calm	68	56.8	146	27.3	0.46
8-05-77	35	Calm	69	63.1	–	38.4	0.43
8-09-77	C	3	86	54.0	151	24.8	0.51
8-15-77	B	8	79	65.9	303	27.0	0.41

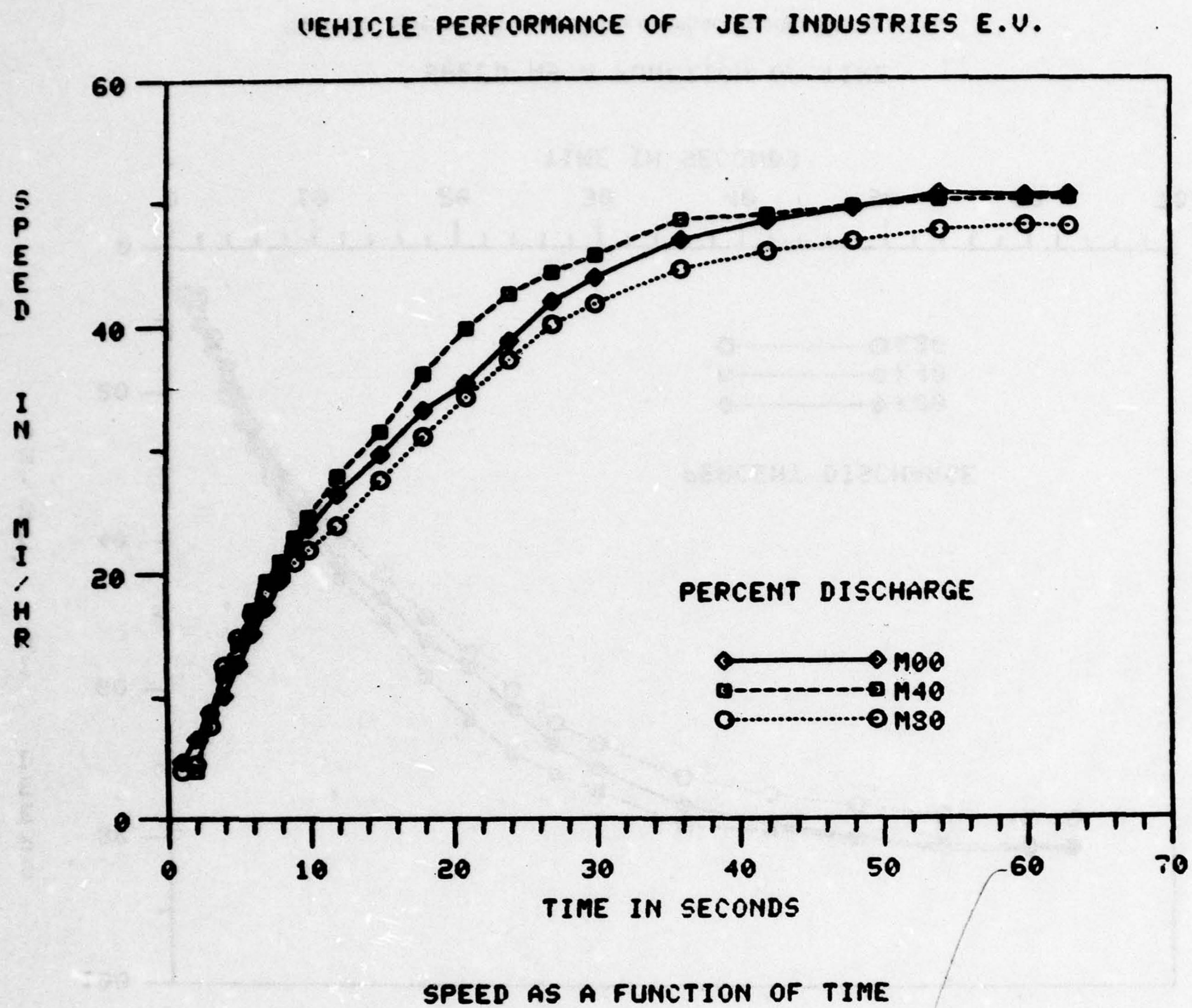

Figure 4A. Speed as a function of time during acceleration (English units).

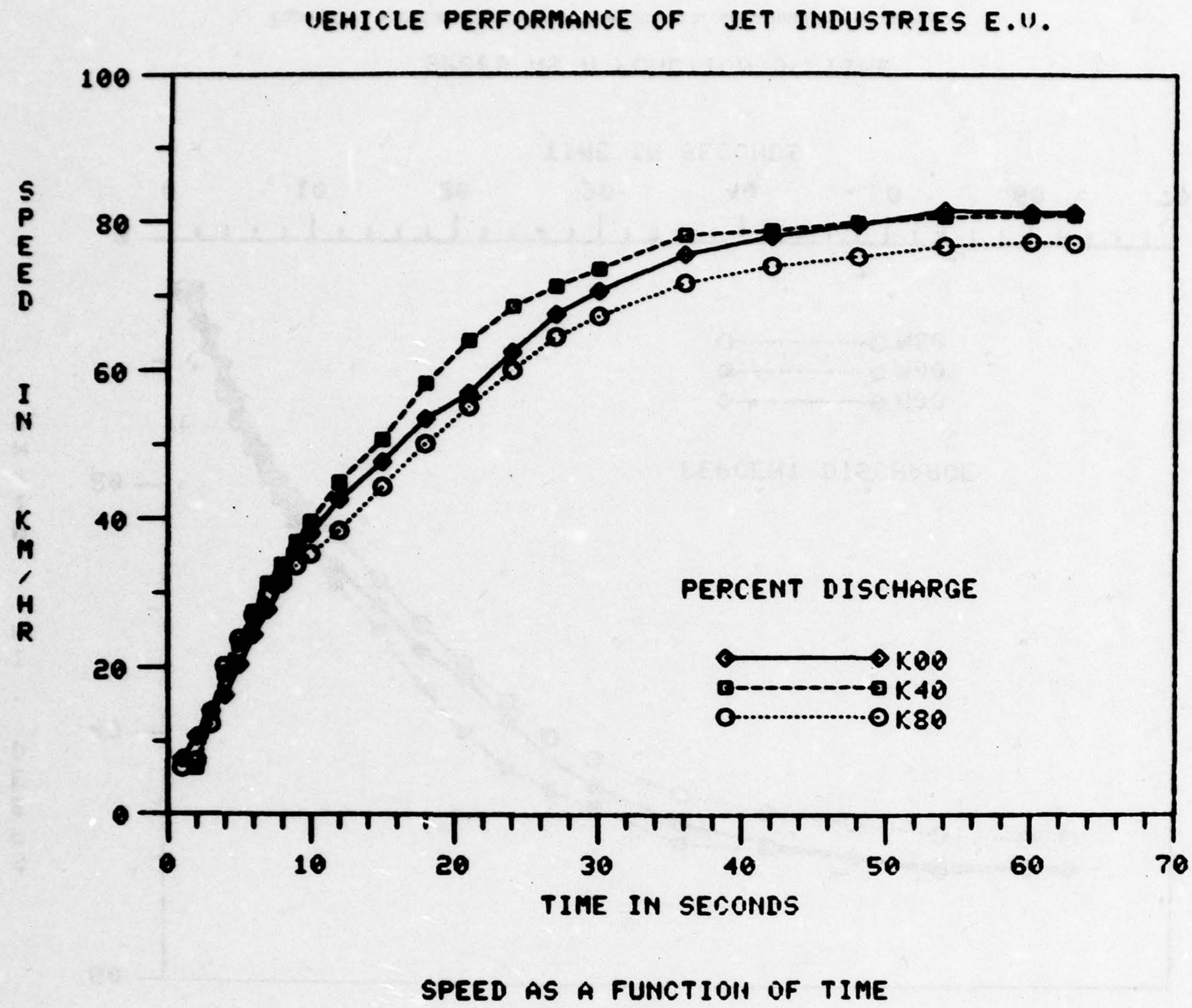

Figure 4B. Speed as a function of time during acceleration (Metric units).

Table 5. Acceleration Test Results at Three States of Charge

Time	Vehicle Speed					
	0% Discharge		40% Discharge		80% Discharge	
(s)	(km/h)	(mi/h)	(km/h)	(mi/h)	(km/h)	(mi/h)
1	7.69	4.78	–	–	6.38	3.96
2	10.70	6.65	6.31	3.92	7.38	4.59
3	14.20	8.82	14.12	8.77	12.40	7.70
4	16.35	10.16	19.17	11.91	20.25	12.58
5	20.52	12.75	23.17	14.40	23.90	14.85
6	24.52	15.24	27.55	17.12	27.03	16.80
7	27.85	17.31	31.32	19.46	29.74	18.48
8	31.35	19.48	33.85	21.03	32.00	19.88
9	35.81	22.25	36.95	22.96	33.71	20.95
10	38.06	23.65	39.60	24.61	35.28	21.92
12	42.57	26.45	44.91	27.91	38.44	23.89
15	47.62	29.60	50.59	31.44	44.31	27.53
18	53.40	33.18	58.10	36.10	50.00	31.07
21	56.81	35.30	63.90	39.71	55.00	34.18
24	62.30	38.71	68.40	42.50	59.84	37.18
27	67.36	41.86	71.12	44.19	64.30	40.00
30	70.44	43.77	73.35	45.58	67.04	41.66
36	75.31	46.80	77.94	48.43	71.52	44.44
42	77.70	48.28	78.52	48.79	73.78	45.84
48	79.40	49.34	79.68	49.51	75.13	46.68
54	81.32	50.53	80.47	50.00	76.56	47.52
60	81.04	50.36	80.54	50.05	77.14	47.93
63	81.17	50.44	80.72	50.16	77.00	47.85

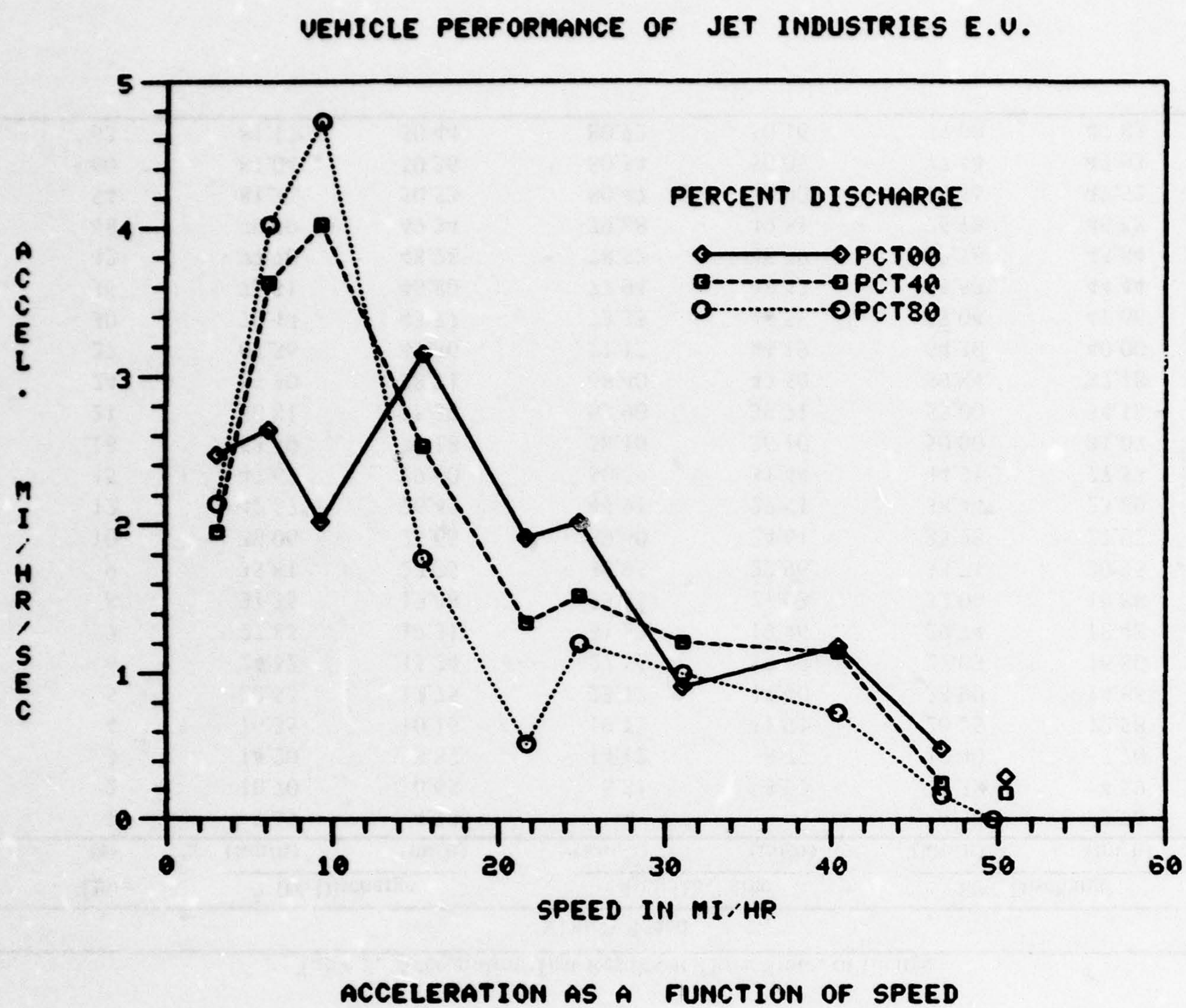

Figure 5A. Acceleration as a function of speed (English units).

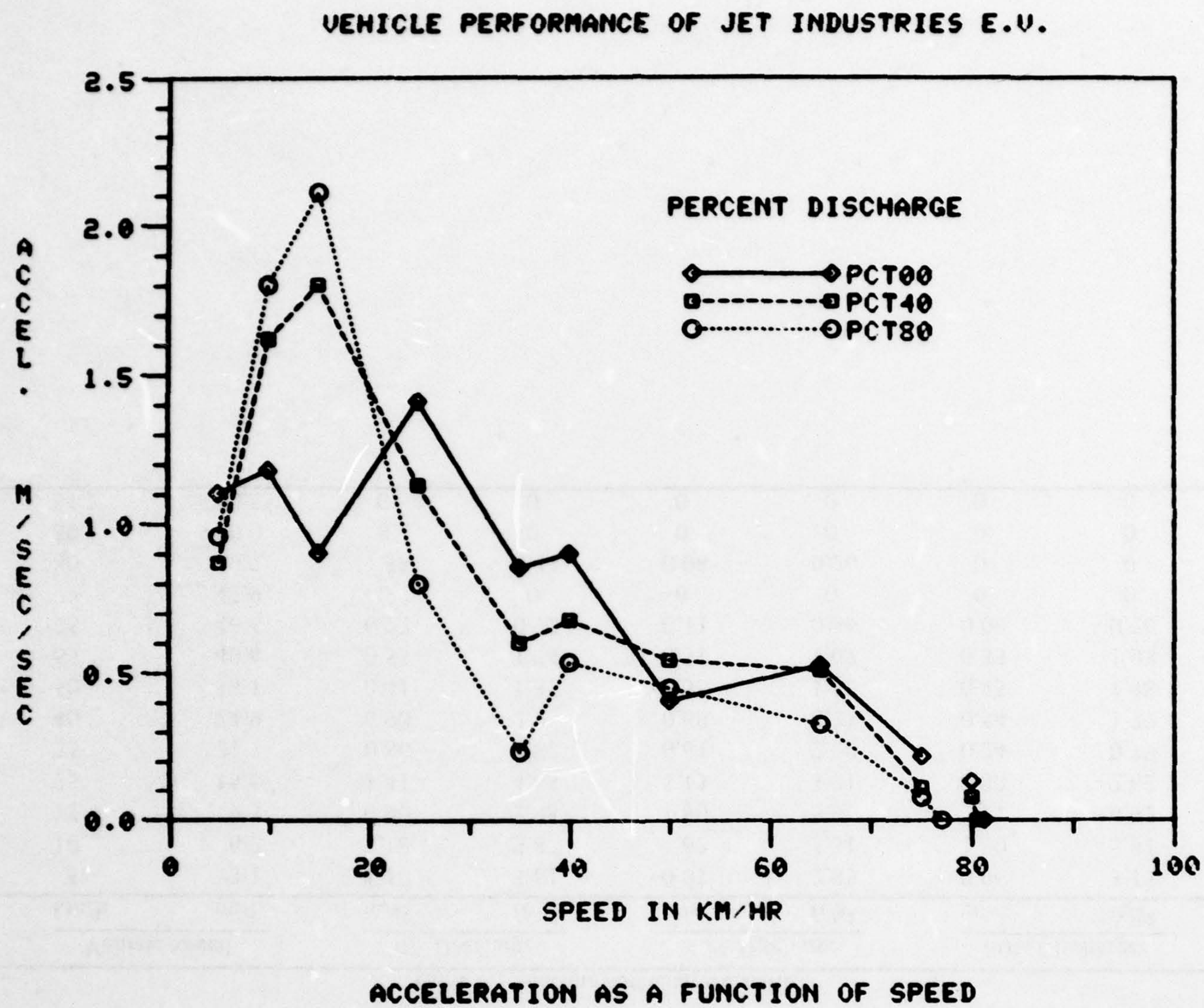

Figure 5B. Acceleration as a function of speed (Metric units).

Table 6. Acceleration Characteristics

Vehicle Speed		0% Discharge		40% Discharge		80% Discharge	
km/h	mi/h	m/s^2	ft/s^2	m/s^2	ft/s^2	m/s^2	ft/s^2
5	3.1	1.10	3.61	0.87	2.85	0.96	3.15
10	6.2	1.18	3.87	1.62	5.31	1.80	5.91
15	9.3	0.90	2.95	1.80	5.91	2.11	6.92
25	15.5	1.41	4.63	1.13	3.71	0.80	2.62
35	21.7	0.86	2.82	0.61	2.00	0.24	0.79
40	24.9	0.90	2.95	0.68	2.23	0.54	1.77
50	33.1	0.41	1.35	0.55	1.80	0.45	1.48
65	40.4	0.53	1.74	0.51	1.67	0.33	1.08
75	46.6	0.22	0.72	0.11	0.36	0.08	0.26
77	47.9	0	0	0	0	0	0
80	49.7	1.33	0.44	0.08	0.26	0	0
80.5	50.0	0	0	0	0	0	0
81.2	50.5	0	0	0	0	0	0

3. **Gradeability.** The maximum vehicle speed on a specific grade is determined from maximum acceleration tests by using the equations:

Gradeability, G, at a speed, $\overline{V}$, in km/h:

$$G = 100 \tan (\sin^{-1} 0.1026\ \bar{a}_n)\ \%;$$

or in English units at a speed, $\overline{V}$, in mi/h:

$$G = 100 \tan (\sin^{-1} 0.0455\ \bar{a}_n)\ \%;$$

where:

$\bar{a}_n$ = acceleration in meters per second squared (mi/h/s).

The resulting maximum grade the Electra-Van can negotiate as a function of speed is shown in Figures 6A and 6B and Table 7.

4. **Road-Energy Consumption.** Road energy is a measure of the energy consumed in overcoming the vehicle's aerodynamic and rolling resistance plus the energy consumed in the differential drive shaft and the portion of the transmission rotating when in neutral. Road energy is obtained during coast-down with the differential being driven only by the wheels.

The road energy consumed by the vehicle at various speeds and the losses in the differential were determined from coast-down tests. Road-energy consumption (E_n) is calculated as megajoules per kilometer from the following equation:

$$E_n = 2.78 \times 10^{-4} W \frac{V_{n-1} - V_n}{t_n - t_{n-1}}, \frac{MJ}{km}$$

or in English units:

$$E_n = 9.07 \times 10^{-5} W \frac{V_{n-1} - V_n}{t_n - t_{n-1}}, \frac{kWh}{mi}$$

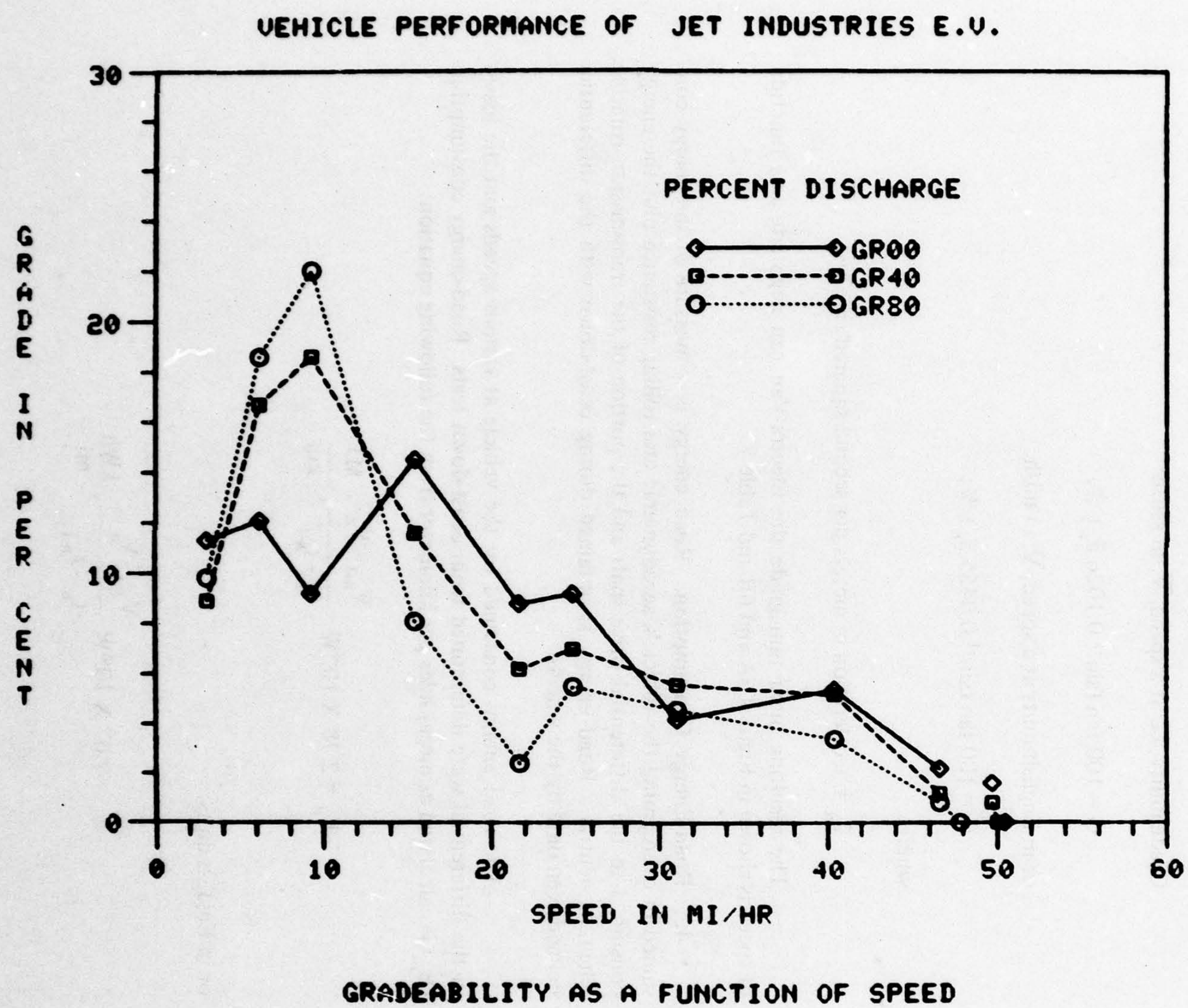

Figure 6A. Gradeability as a function of speed (English units).

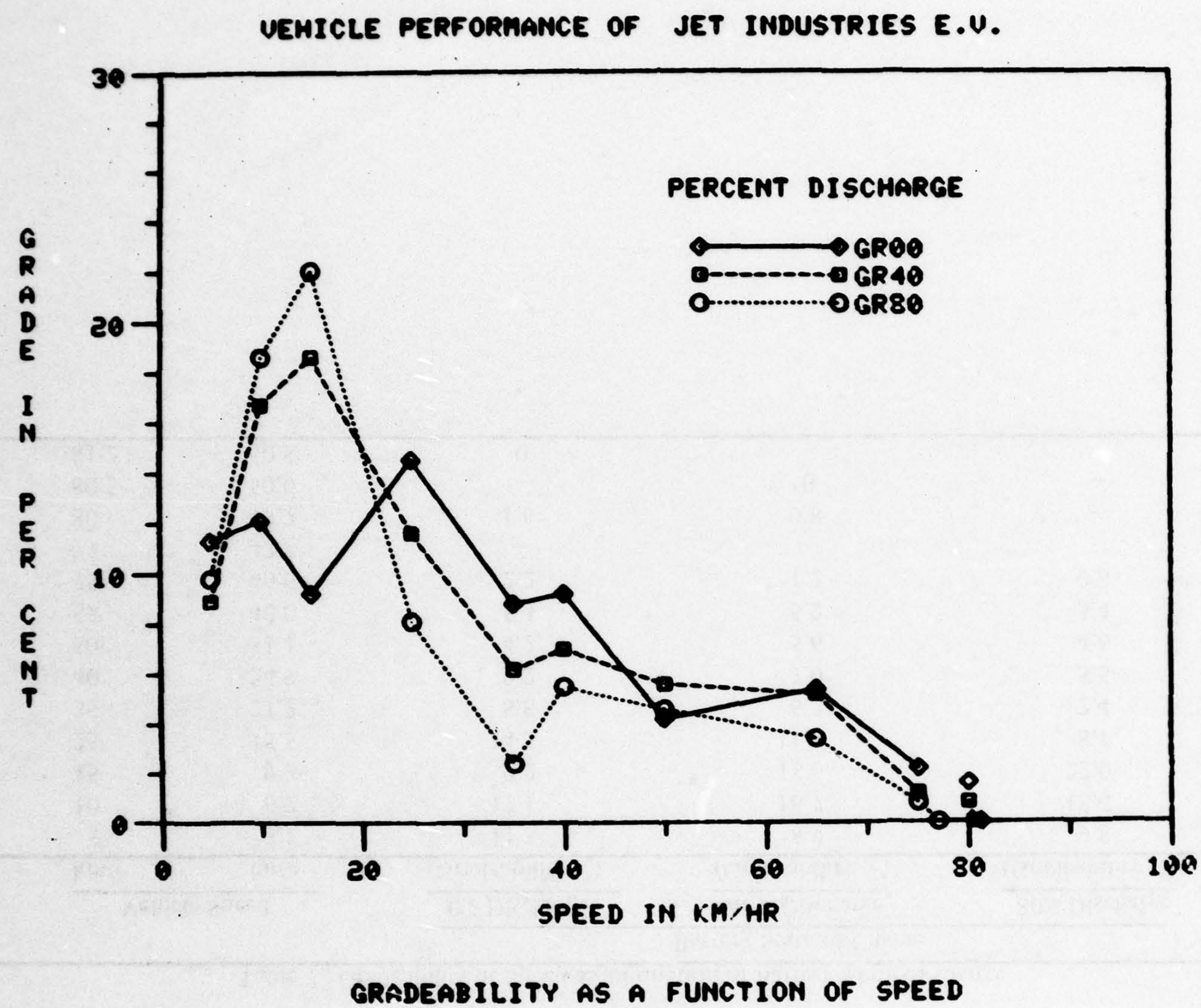

Figure 6B. Gradeability as a function of speed (Metric units).

Table 7. Gradeability at Speed as a Function of Battery State of Charge

Vehicle Speed		Battery State of Charge		
		0% Discharge	40% Discharge	80% Discharge
km/h	mi/h	(Gradeability %)	(Gradeability %)	(Gradeability %)
5	3.1	11.3	8.9	9.8
10	6.2	12.1	16.7	18.6
15	9.3	9.2	18.6	22.0
25	15.5	14.5	11.6	8.1
35	21.7	8.8	6.2	2.4
40	24.9	9.2	7.0	5.5
50	31.1	4.2	5.6	4.6
65	40.0	5.4	5.2	3.4
[illegible]	46.6	2.2	1.2	0.8
[illegible]	47.8	–	–	–
80	49.7	1.6	0.8	–
80.5	50.0	–	0	–
81.2	50.5	0	–	–

where:

V = vehicle speed in km/h (mi/h)
t = time (s)

The results for the road-energy determination are shown in Figures 7A, B, and C and Table 8.

5. **Road-Power Requirements.** The road power is a measure of vehicle aerodynamic and rolling resistance plus the differential, drive shaft, and a portion of the transmission's power loss.

The road power, P_n, required to propel a vehicle at various speeds is also determined from the coast-down tests. The following equations are used:

$$P_n = 3.86 \times 10^{-5} W \frac{V^2_{n-1} - V^2_n}{t_n - t_{n-1}}, \text{ kW;}$$

or in English units:

$$P_n = 6.08 \times 10^{-5} W \frac{V^2_{n-1} - V^2_n}{t_n - t_{n-1}}, \text{ hp.}$$

The results of road-power calculations are shown in Figures 8A and 8B and Table 9.

6. **Indicated-Energy Consumption.** The vehicle-indicated-energy consumption is defined as the energy required to recharge the battery after a test divided by the vehicle range achieved during the test where the energy is measured as the input to the battery charger.

The energy input to the battery charger was measured with a residential kilowatt-hour meter following each range test. Some overcharge of the batteries was usually required in order to assure that all cells of the battery were fully charged and the pack was equalized. The energy usage was based on field data acquired with an off-board Lester Corporation charger.

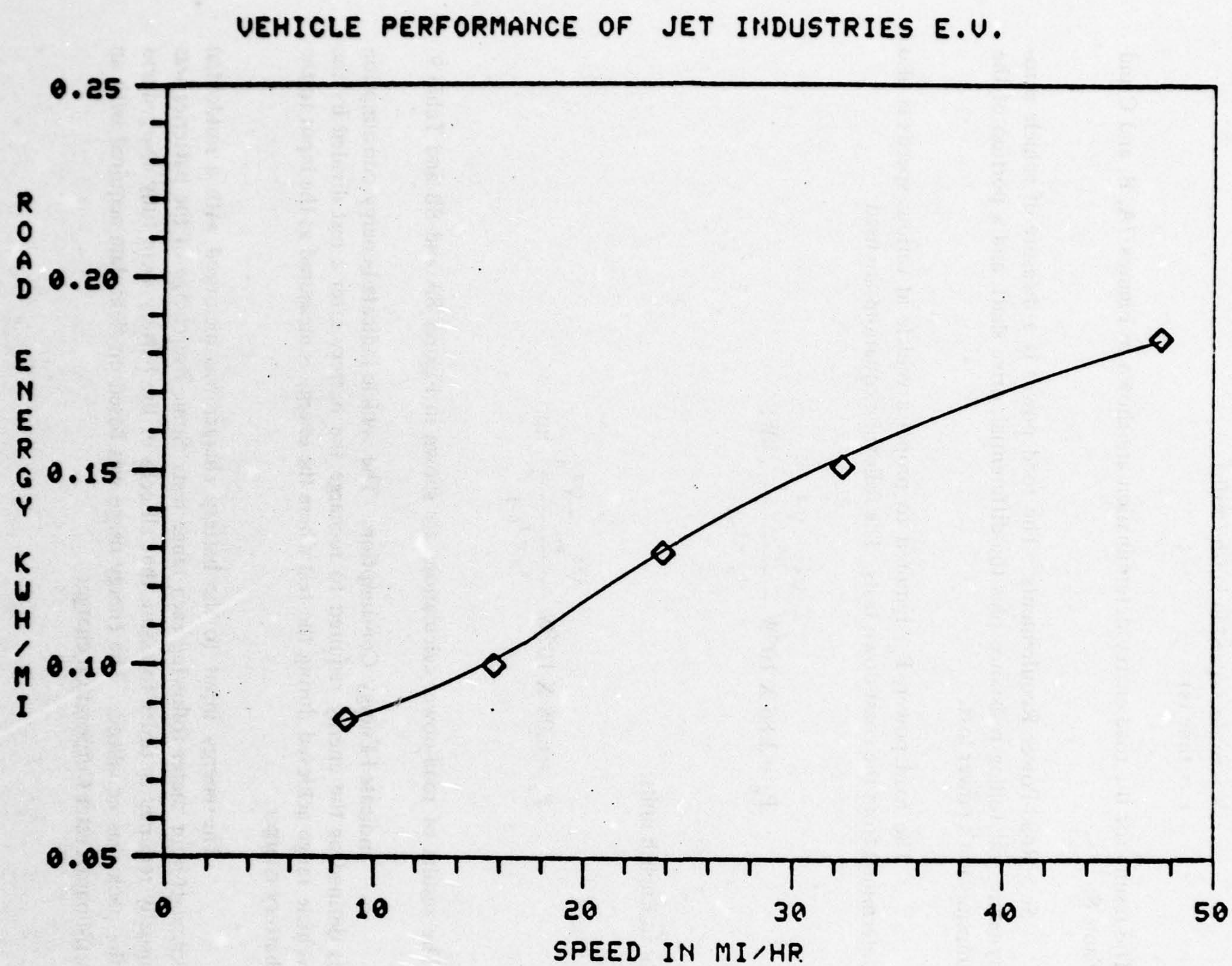

Figure 7A. Road energy as a function of speed (English units).

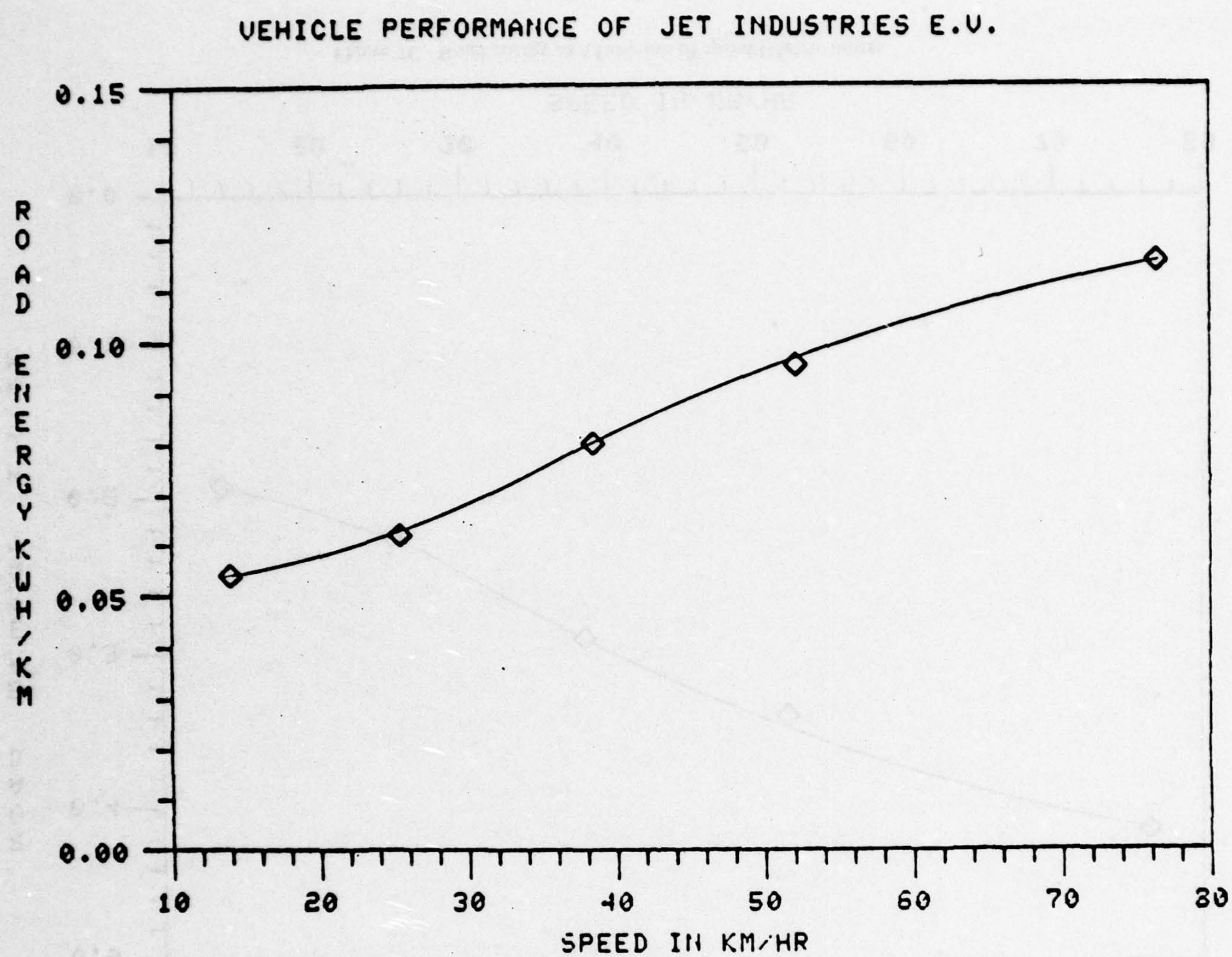

Figure 7B. Road energy as a function of speed (Metric units).

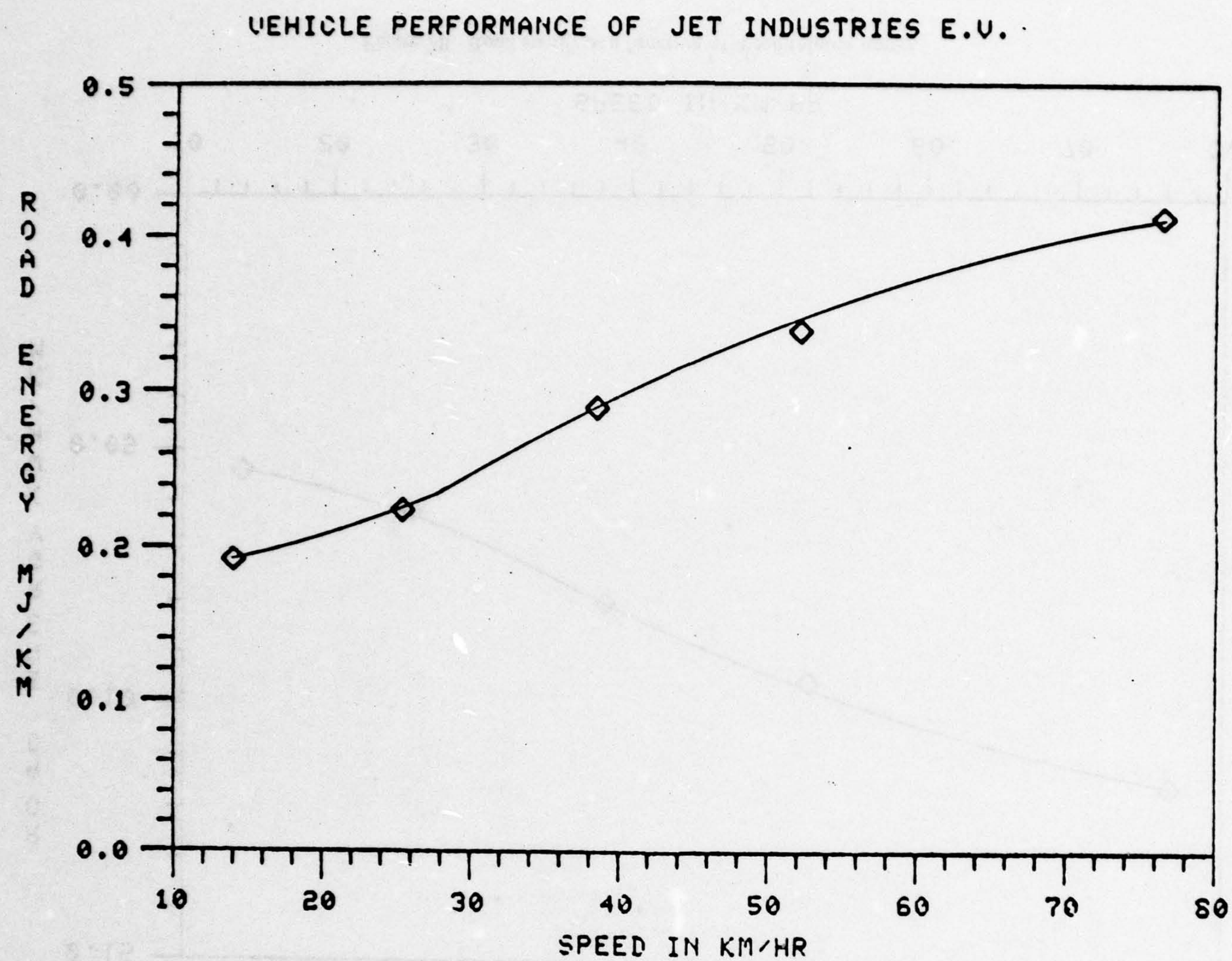

Figure 7C. Road energy as a function of speed (Metric units).

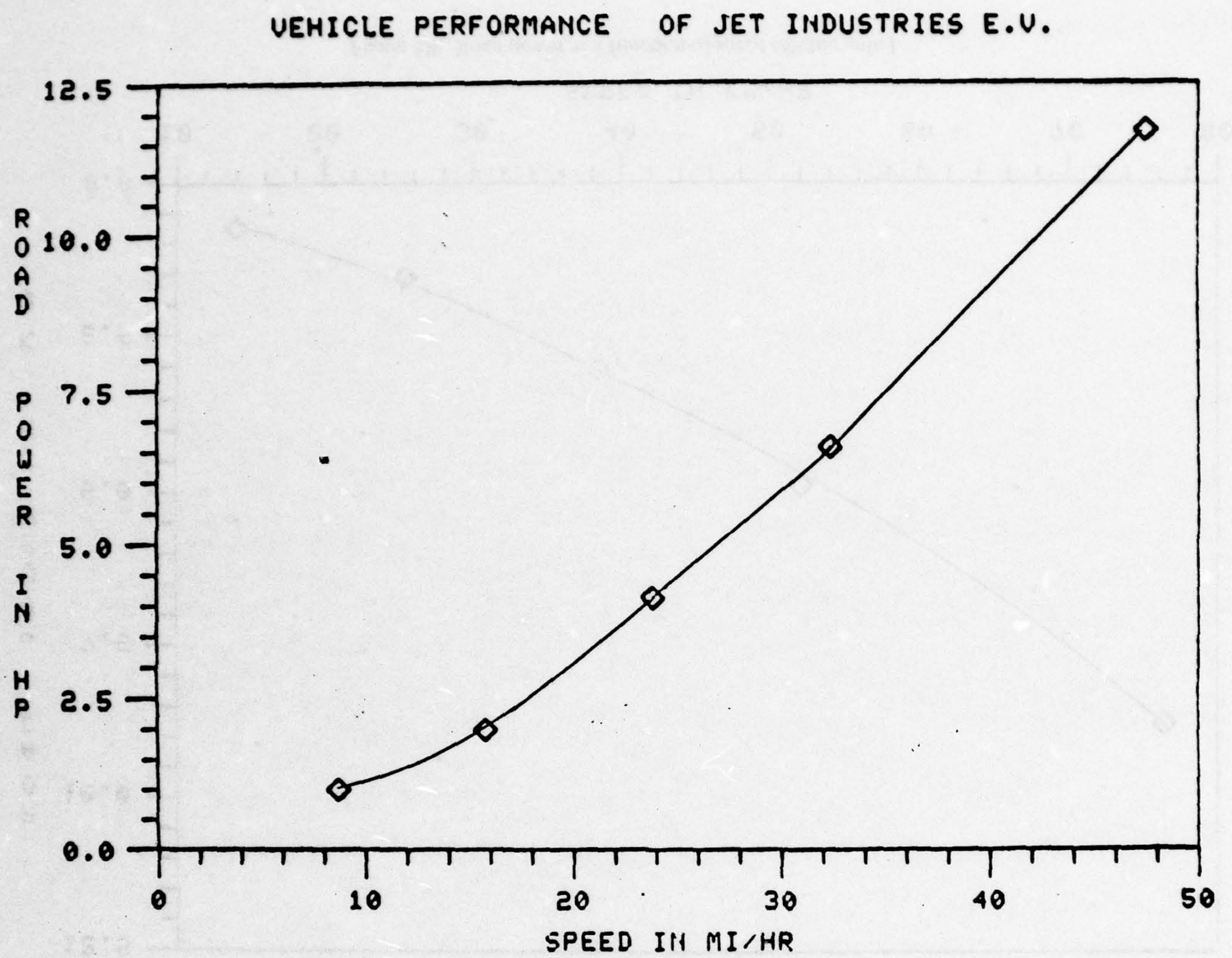

Figure 8A. Road power as a function of speed (English units).

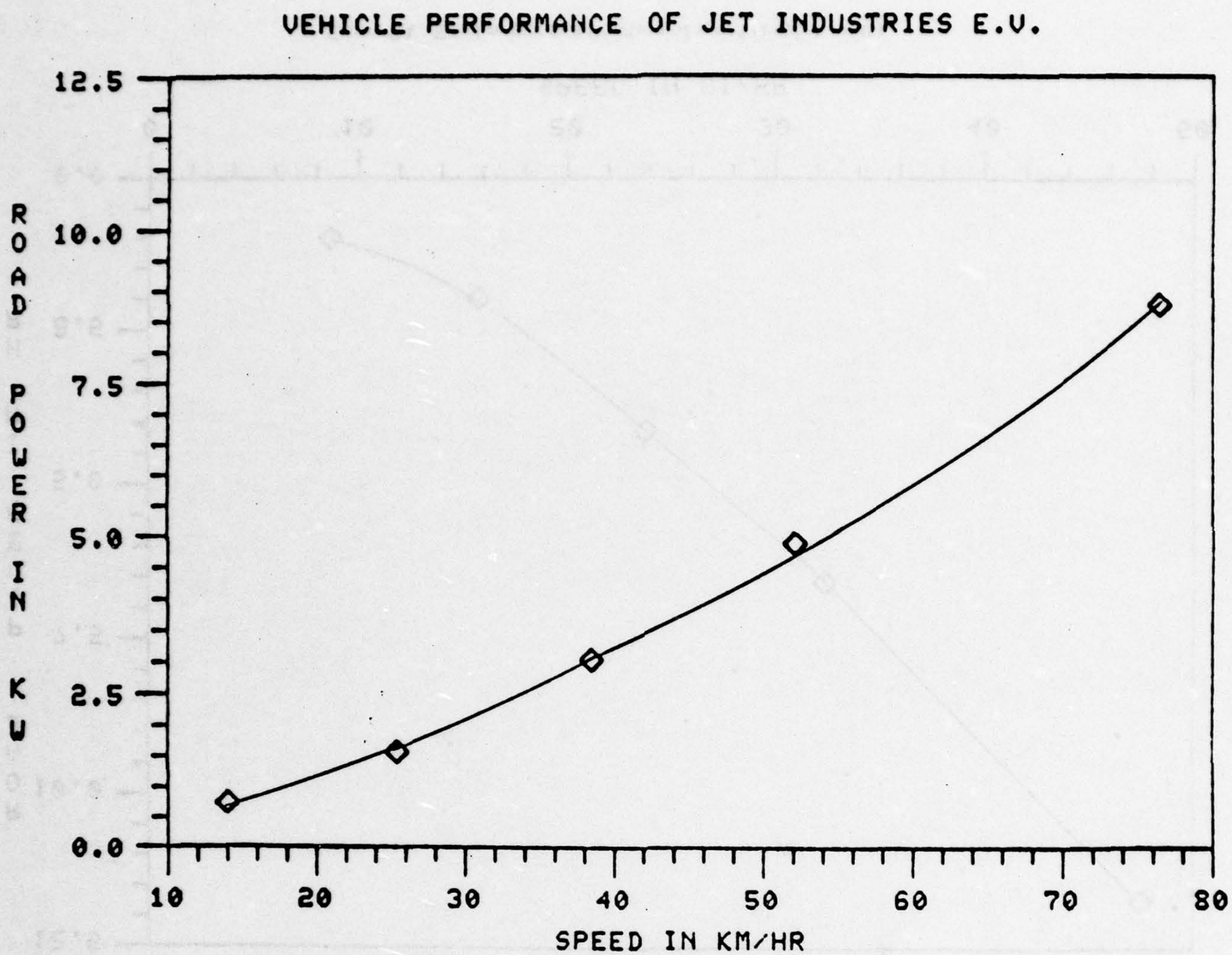

Figure 8B. Road power as a function of speed (Metric units).

Table 8. Road Energy Consumption

Vehicle Speed		Road Energy		
(km/h)	(mi/h)	(MJ/km)	(kWh/km)	(kWh/mi)
76.4	47.5	0.412	0.115	0.184
65.0	40.0	0.456	0.127	0.204
52.2	32.4	0.338	0.095	0.151
38.5	23.9	0.289	0.08	0.129
25.4	15.8	0.224	0.062	0.100
14.0	8.7	0.192	0.054	0.086

Table 9. Road Power Requirements

Vehicle Speed		Road Power Required	
(km/h)	(mi/h)	(kw)	(hp)
71.6	44.5	8.79	11.7
58.2	36.2	8.25	11.0
45.8	28.5	4.9	6.56
31.1	19.3	3.06	4.14
19.6	12.2	1.58	2.10
8.3	5.2	0.75	1.0

Table 10. Jet Industries E.V., Constant-Speed Battery Data

Characteristic	25-mi/h test (First 25%)	25-mi/h test (Last 25%)	35-mi/h test (First 25%)	35-mi/h test (Last 25%)
$\bar{I}_B$ Average Battery Current (A)	51.3	49.8	78.8	72.1
$\bar{V}_B$ Average Battery Voltage (V)	104.3	95.52	103.1	94.9
$\bar{P}_B$ Average Battery Power (kW)	5.35	4.76	8.12	6.84
Total Energy Removed from Battery	15.9 kWh		14.1 kWh	

VIII. COMPONENT PERFORMANCE AND EFFICIENCY

1. Battery Characteristics.

a. **Manufacturer's Data.** The batteries supplied with the Electra-Van vehicle were eighteen, 6-volt, lead-acid modules, type EV106, from the ESB Corporation, rated 132 ampere-hours at 75 amperes.

b. **Battery Acceptance.** Prior to initiation of road tests, the batteries supplied by the vehicle manufacturer were tested for battery capacity and terminal integrity as specified in Appendix E of MERADCOM Report 2244.[5] The capacity check was performed on the batteries using a thyristor-controlled discharge unit.[6] Since the measured capacity was 135 ampere-hours at a discharge rate of 75 amperes to 1.70 volts per cell, more than 100% of the manufacturer's rated capacity, the battery was acceptable. As shown in Figure 9, the battery voltage at the initiation of discharge was 115.0 volts and decayed gradually to 91.80 volts at the end of the test.

In lieu of the 5-minute, terminal-integrity test, all terminals and terminal connections were cleaned and inspected.

2. Constant Vehicle Speed Battery Performance. During the road tests, battery current was constantly monitored. Presented in Figures 10A and 10B and Table 10 are the battery characteristics during the 40-km/h (25-mi/h) range test 28 July 1977 and the 56.3 km/h (35-mi/h) range test run on 5 August 1977. The average battery current, voltage, and power during the first 25% of the vehicle's range are shown in Figure 10A. Similar battery-performance data during the last 25% of the vehicle's range are shown in Figure 10B. Battery power decreases toward the end of the test which is probably due to the reduced power requirements as the temperature of the mechanical drive train components and associated lubricants increases during the test.

3. Battery Performance – Maximum Acceleration. Battery-performance data at selected times during the maximum-acceleration test for three depths of battery discharge are presented in Table 11.

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[5] E. J. Dowgiallo, Jr.; C. E. Bailey, Jr.; I. R. Snellings; and W. H. Blake; "Baseline Tests of the EVA Metro Electric Passenger Vehicle," MERADCOM Report 2244 (July 1978).

[6] E. J. Dowgiallo, Jr.; J. B. O'Sullivan; I. R. Snellings; and R. B. Anderson, High Power Facility for Testing Electrochemical Power Sources. Princeton, New Jersey; Journal of the Electrochemical Society, Vol. 121, No. 9, September 1974.

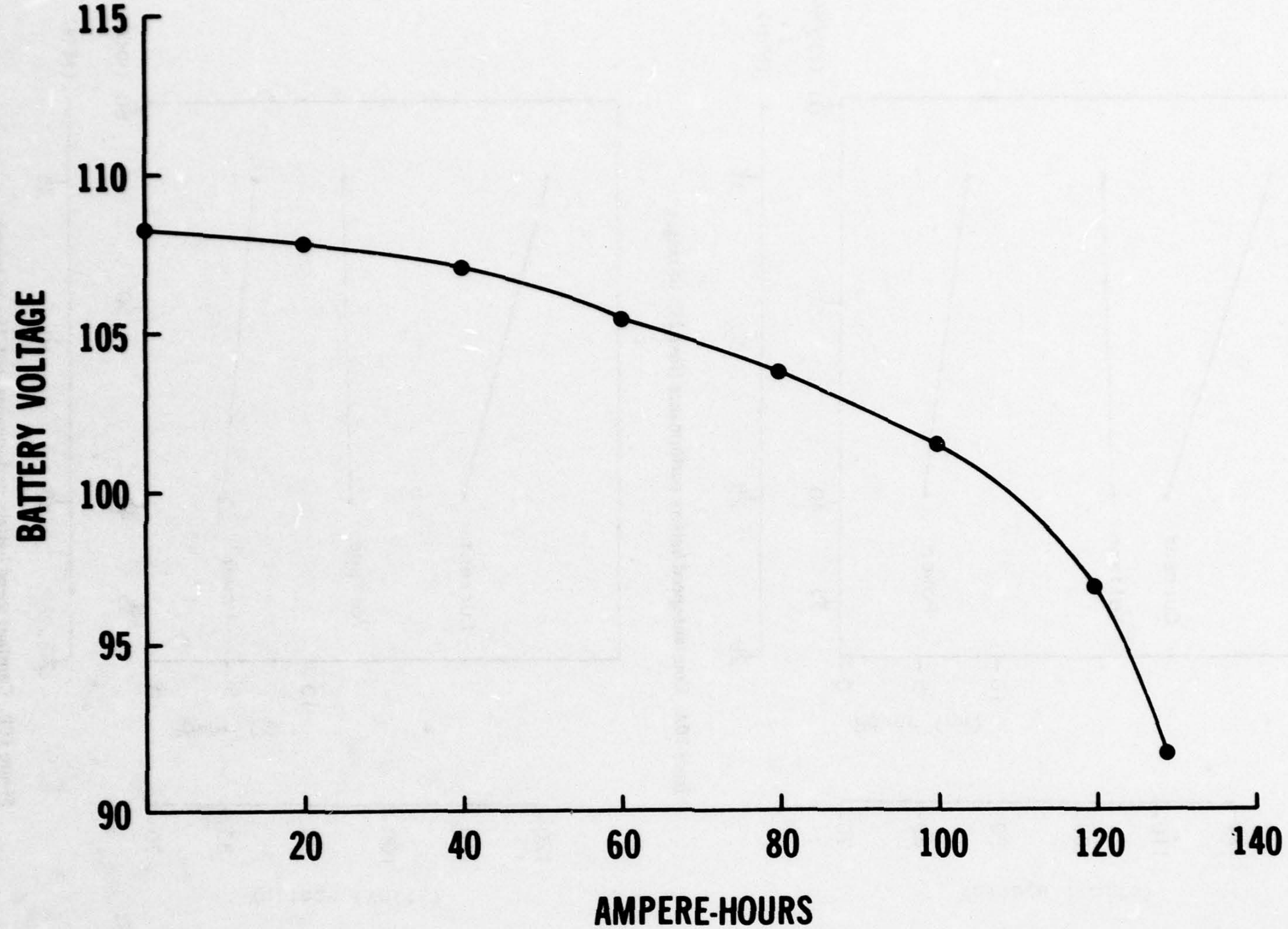

Figure 9. Battery voltage as a function of capacity removed.

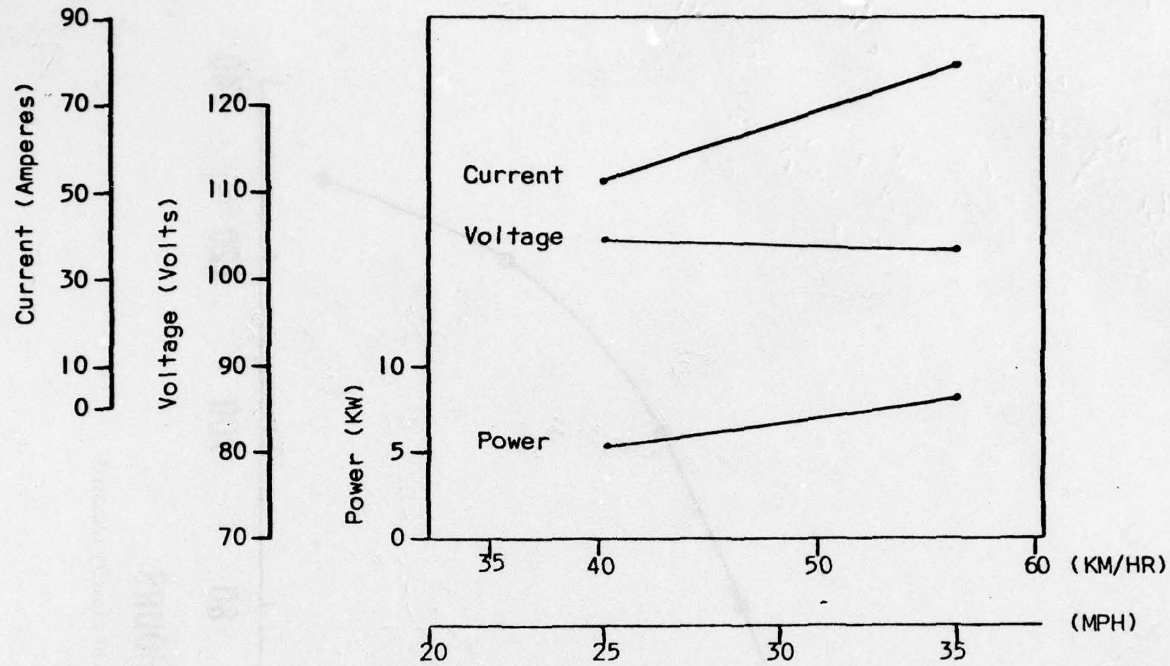

Figure 10A. Constant-speed battery performance (first 25% of range).

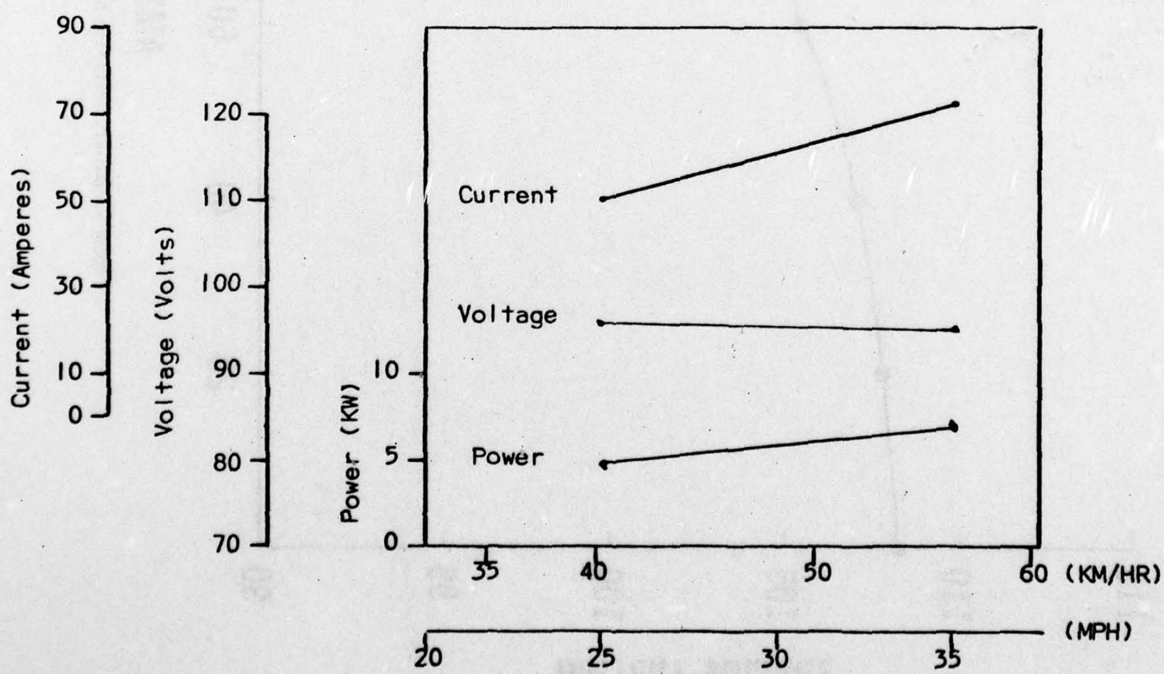

Figure 10B. Constant-speed battery performance (last 25% of range).

Table 11. Battery Performance – Maximum Acceleration

Time	Speed		Current	Voltage	Power	Discharged
(s)	(mi/h)	(km/h)	(A)	(V)	(kW)	(%)
10	23.7	38.1	439	94.0	41.3	0
20	34.6	55.7	442	95.4	42.2	0
40	47.4	76.3	361	97.1	35.1	0
60	50.3	81.0	315	98.4	31.0	0
10	24.6	39.6	438	93.8	41.1	40
20	38.5	62.0	518	91.3	47.3	40
40	48.5	78.1	314	96.6	30.3	40
60	50.0	80.5	283	97.3	27.5	40
10	21.9	35.3	307	93.0	21.3	80
20	33.1	53.3	497	86.3	42.9	80
40	45.4	73.1	315	91.3	28.8	80
60	47.9	77.1	284	92.5	26.3	80

4. **Battery Performance – Driving Cycle.** The battery current, voltage, and power and the vehicle speed for the third and next to last cycle of the SAE "B" and "C" (start/stop) schedules are shown in Figures 11 A-H and 12 A-D, respectively. Figures 11 A-D were performed with the driver shifting with the clutch and Figures 11 E-G, "speed shifting." Speed shifting was performed by rapidly shifting with the clutch with the accelerator pedal remaining depressed. A time delay built into the controller was avoided by holding the accelerator pedal down, thereby using less current during shifting . The point at which the clutch was shifted from first gear to second is shown in Figures 11 A and C for the third J227a schedule B cycle. In Figures 11 E and G, the shift point for the next to the last cycle is shown. The shift point for the third cycle cannot be determined. The driver apparently did not speed shift properly and completed the shift from first to second gear after about 12 seconds. The schedule "C" runs in Figures 12 A-D are averages of two separate runs. In Figures 12 A and C, the points at which the clutch was shifted are shown for the third J227a schedule C cycle. The driver speed shifted on each run. The total number of start/stops, distance traveled, and other data on the battery and drive cycles are given in Table 12.

5. **General Battery Performance.** The fully charged (temperature corrected) battery electrolyte specific gravities during the driving tests ranged from 1.270 to 1.295 and the fully discharged specific gravities, from 1.110 to 1.120. The battery temperature had a tendency to increase from ambient at the start of the test to about 10°C (17°F) above ambient at the end of the test.

6. **Braking Tests.** Braking tests were performed from speeds of 48.3 km/h (30 mi/h) and 64.4 km/h (40 mi/h). The required stopping distance criteria of 17.4 and 29.3 m (57 and 96 feet) respectively were complied with.

IX. DRIVER REACTION

Performance was good in general. The battery enclosure was made out of a light metal that could be stressed enough by a heavy weight to short the battery terminals.

The rear batteries do not have sufficient protection to survive even a minor rear-end impact. The front seat has no adjustment for comfort of different size drivers.

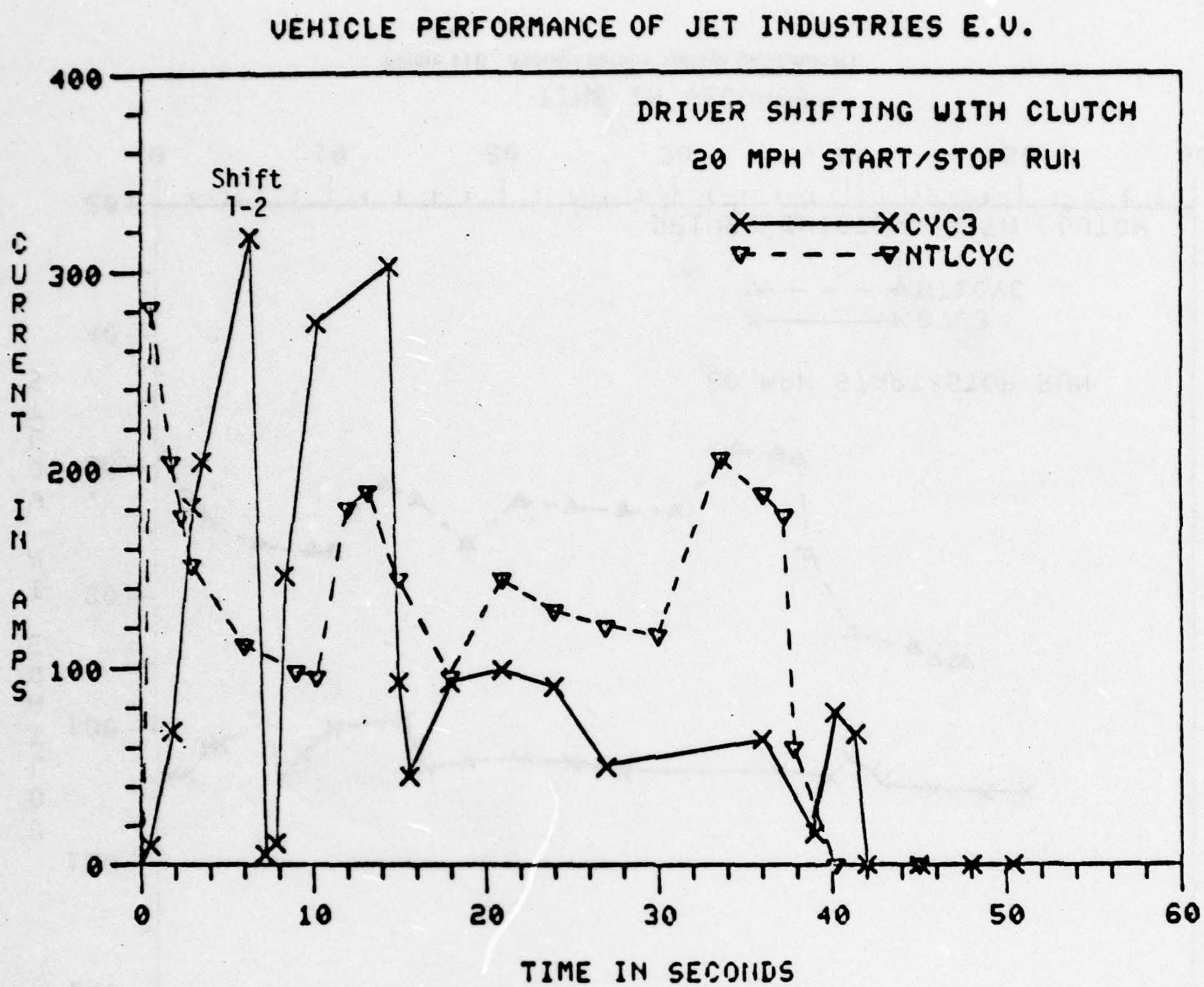

Figure 11A. Average battery current (Schedule B).

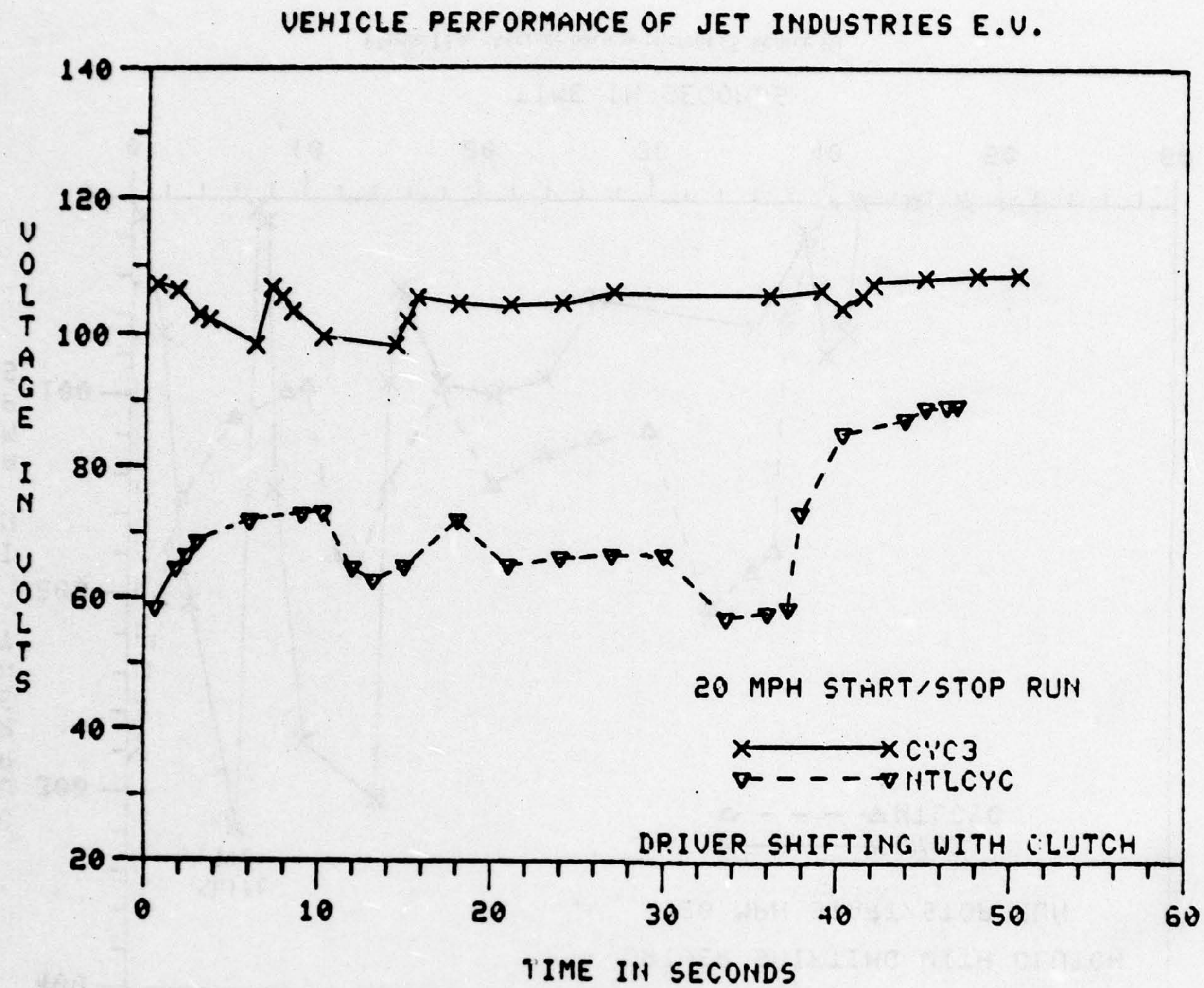

Figure 11B. Average battery voltage (Schedule B).

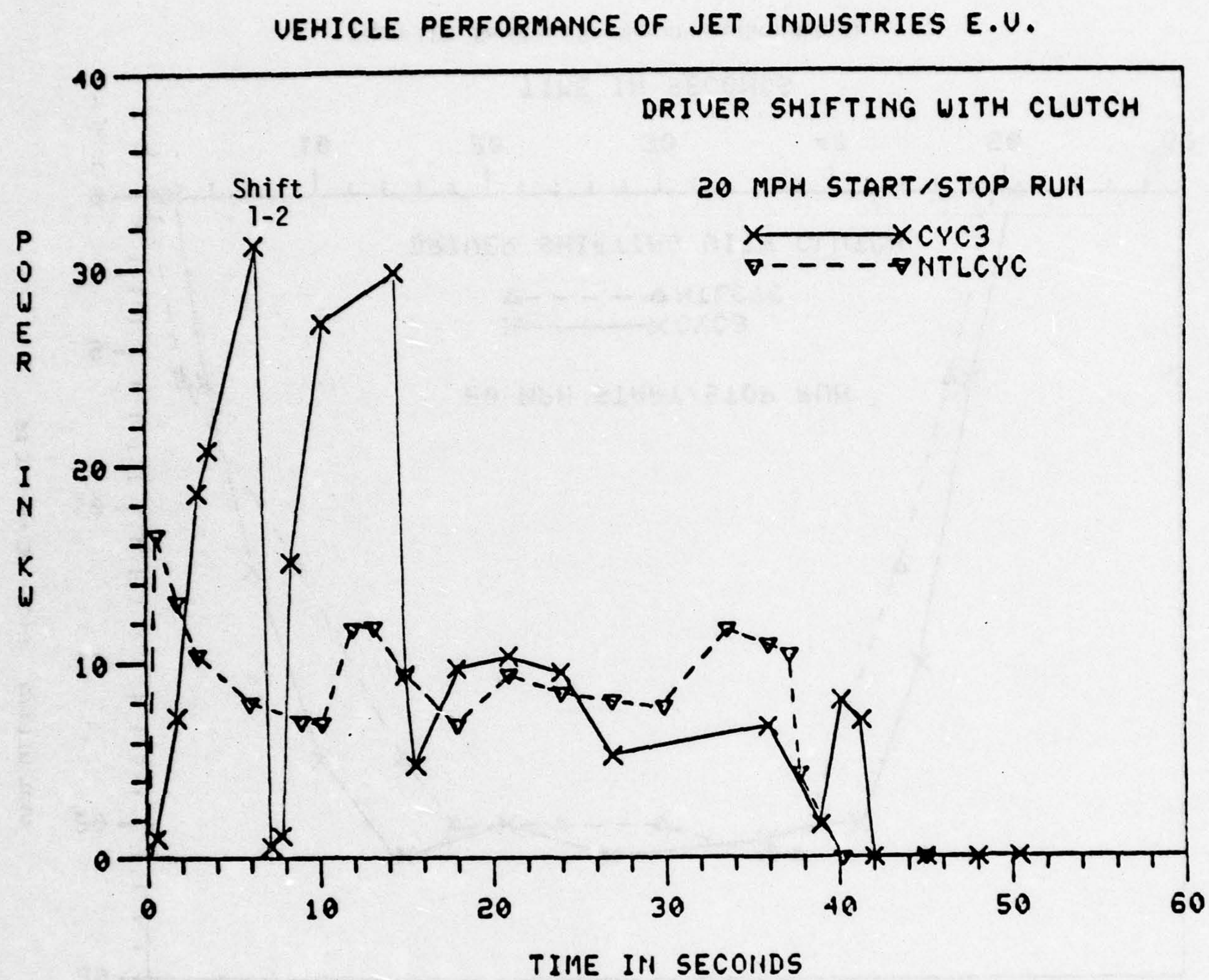

Figure 11C. Average battery power (Schedule B).

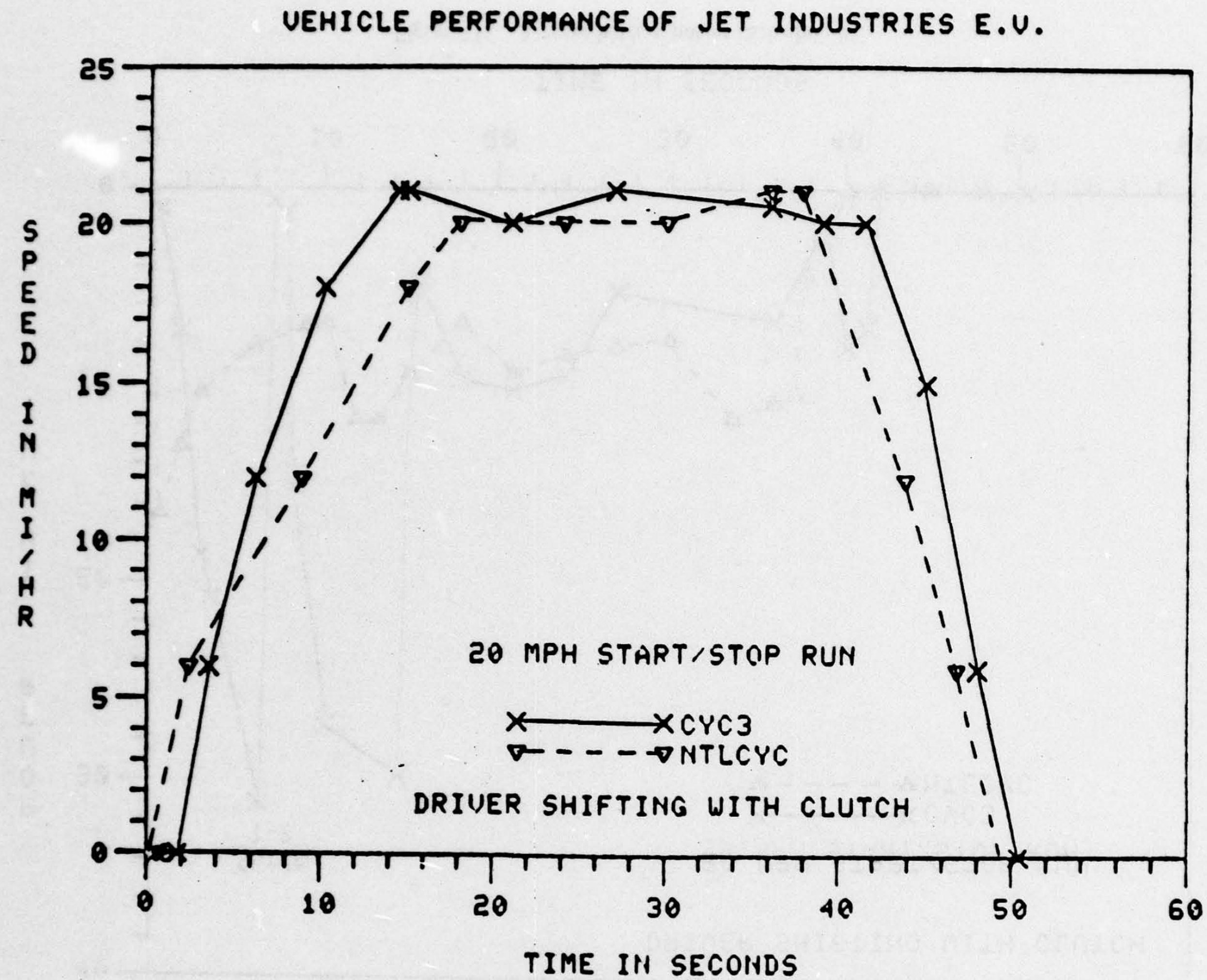

Figure 11D. Speed as a function of time (Schedule B).

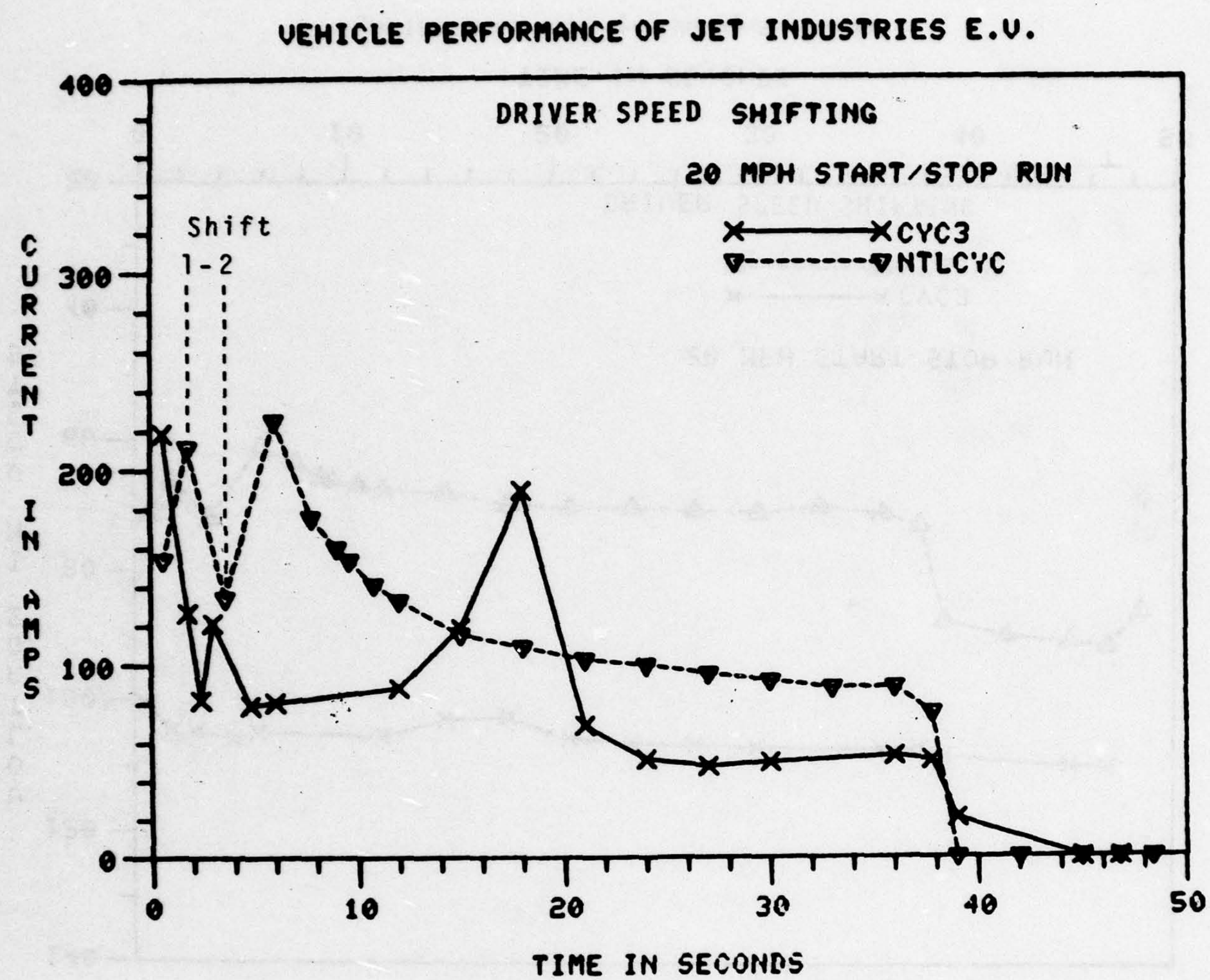

Figure 11E. Battery current speed shifting (Schedule B).

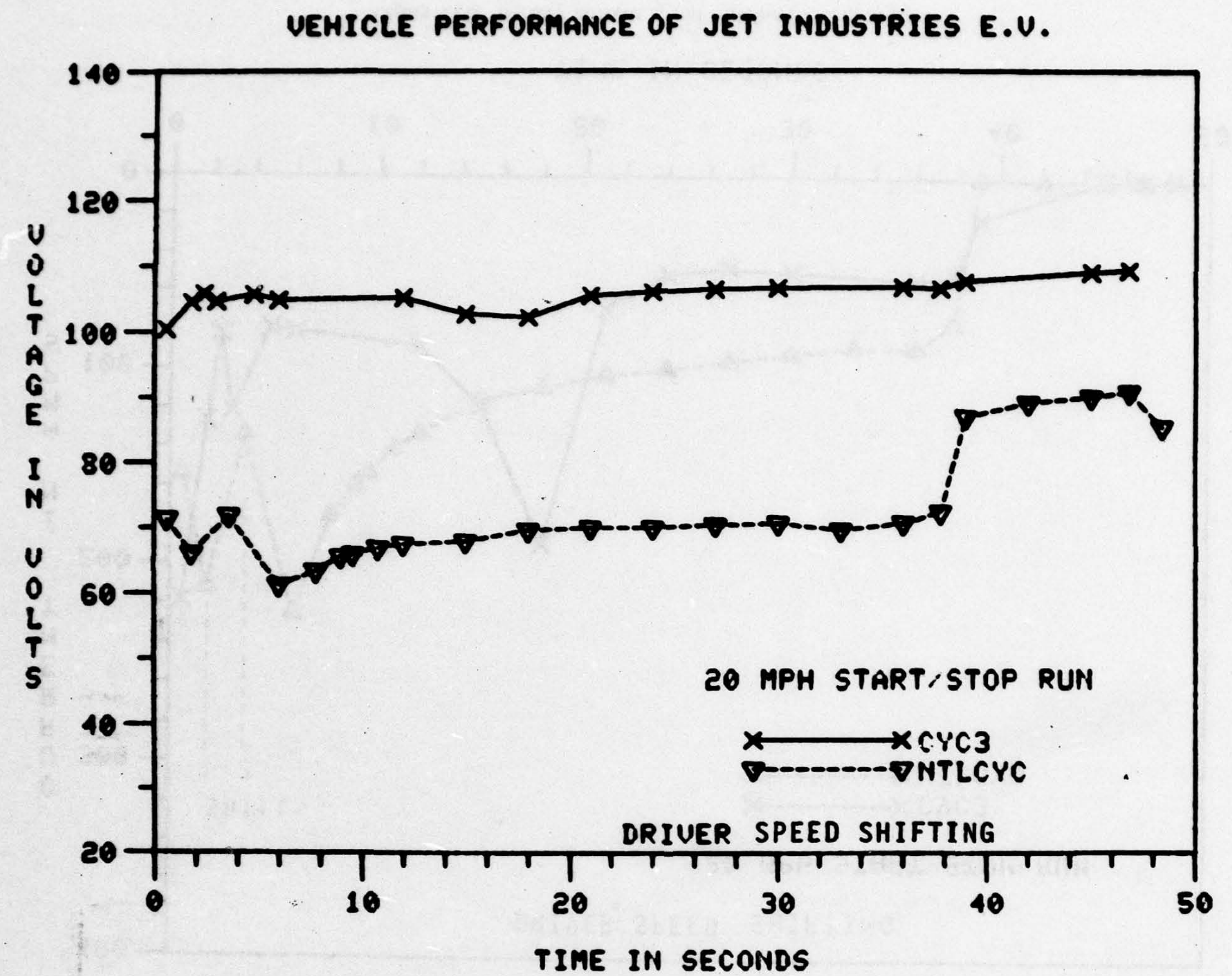

Figure 11F. Battery voltage speed shifting (Schedule B).

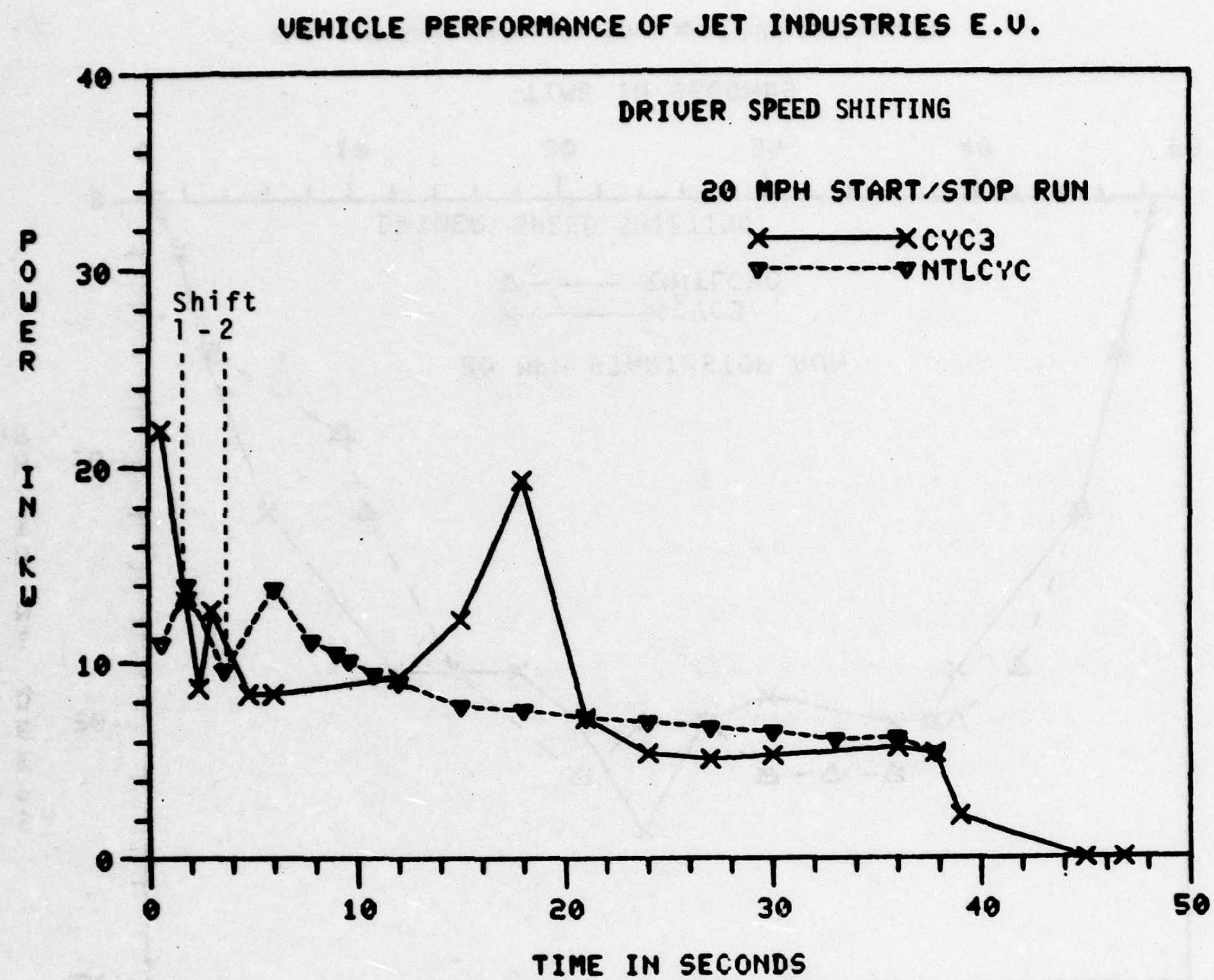

Figure 11G. Battery power, speed shifting (Schedule B).

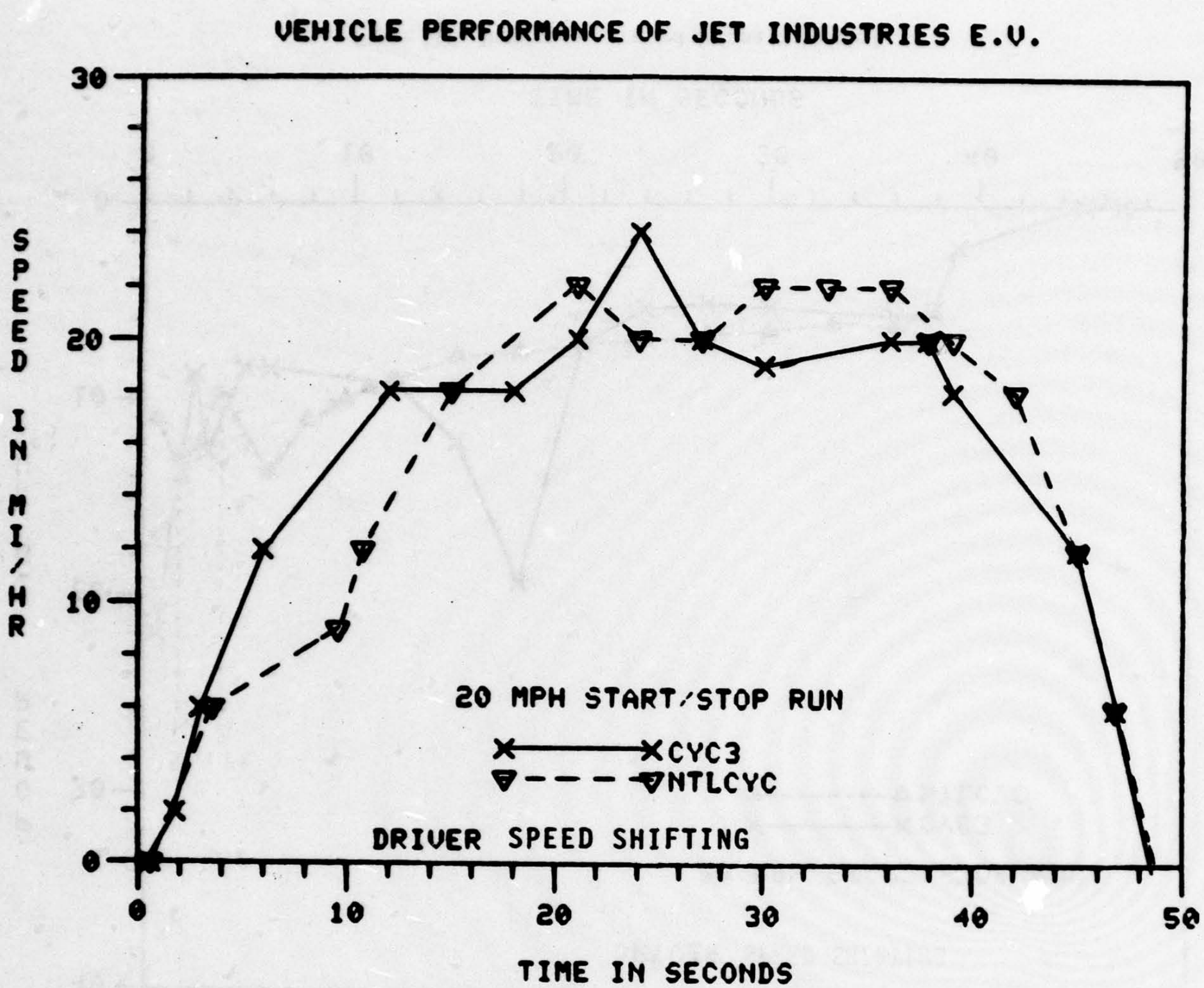

Figure 11H. Speed as a function of time, speed shifting (Schedule B).

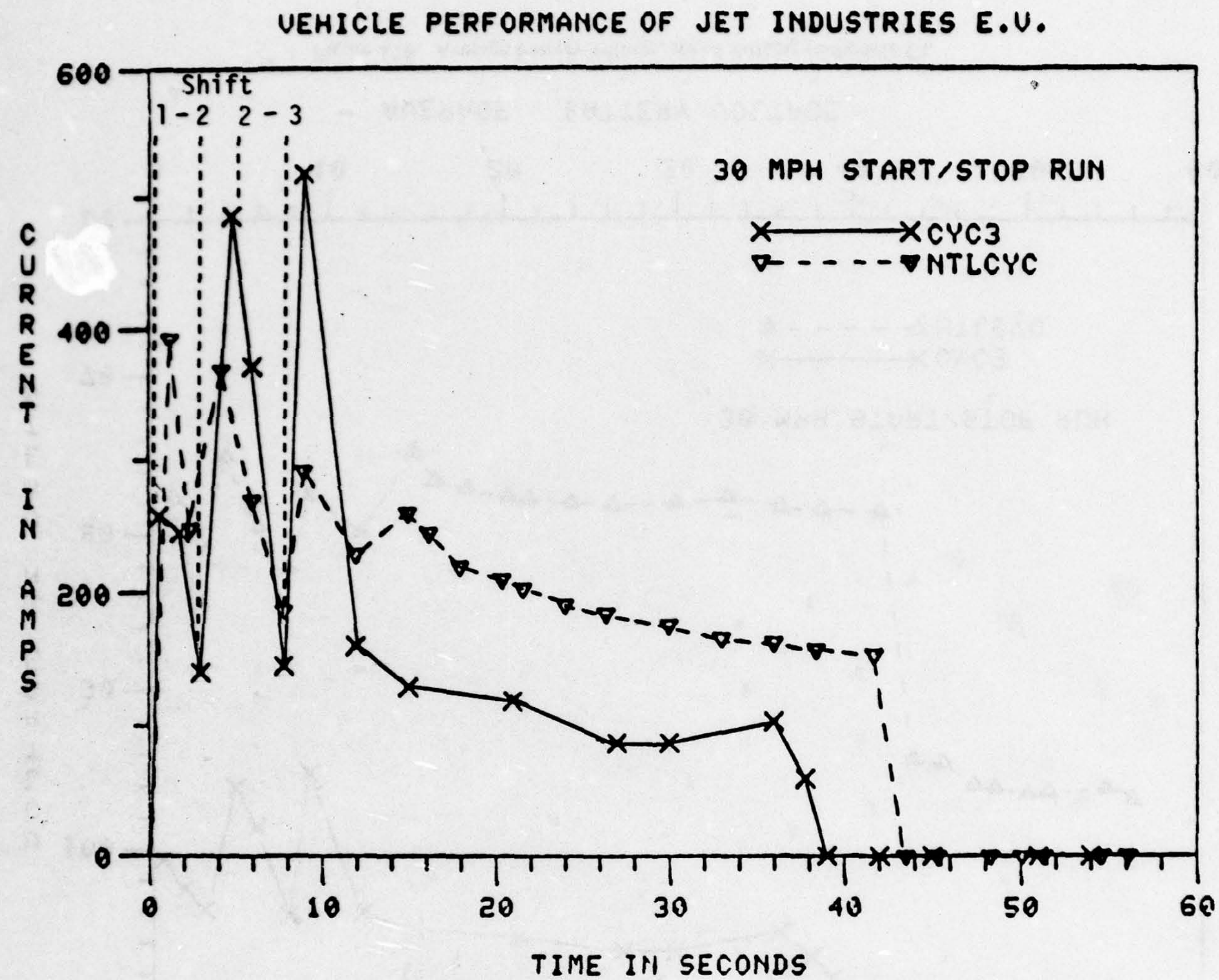

Figure 12A. Average battery current, speed shifting (Schedule C).

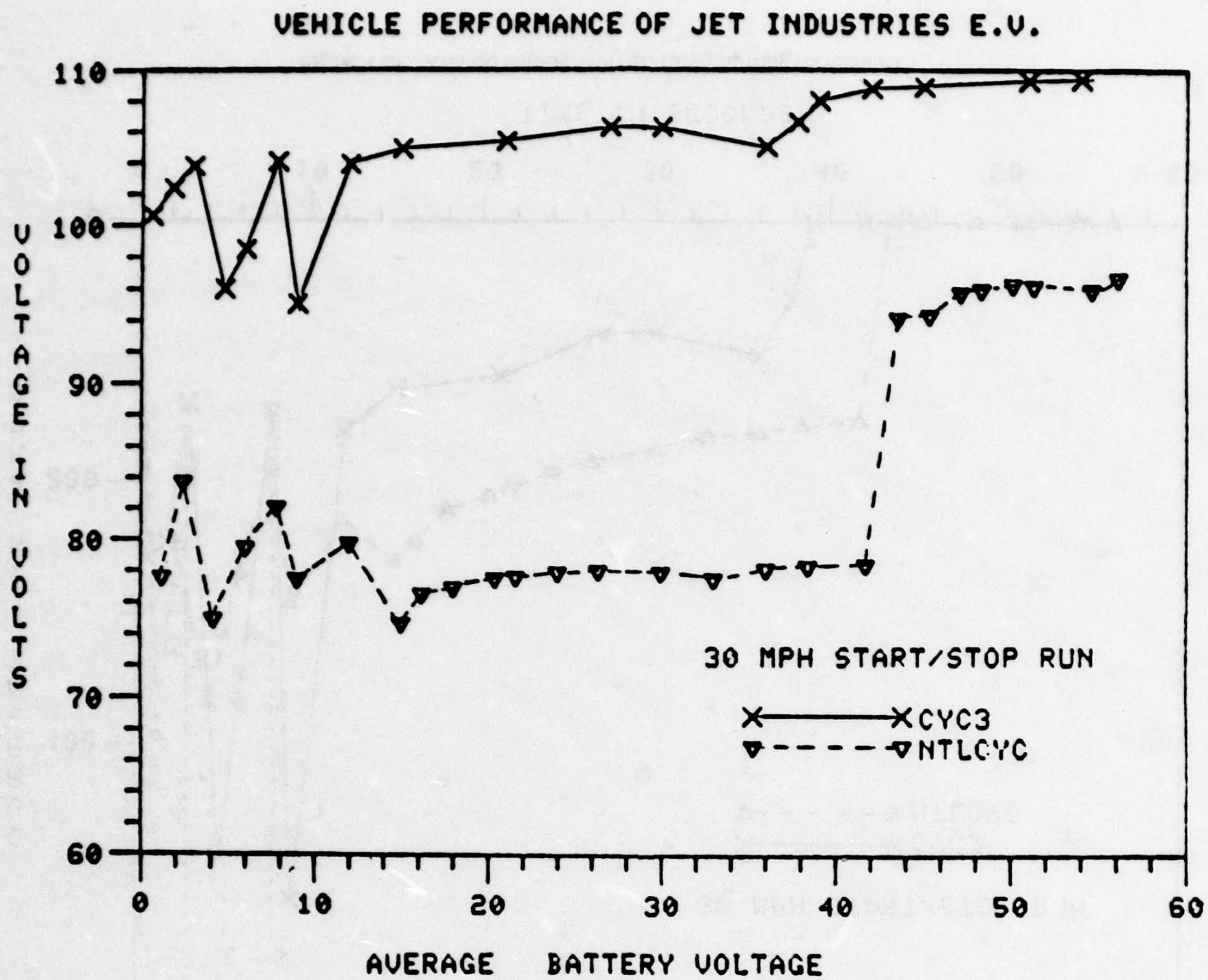

Figure 12B. Average battery voltage, speed shifting (Schedule C).

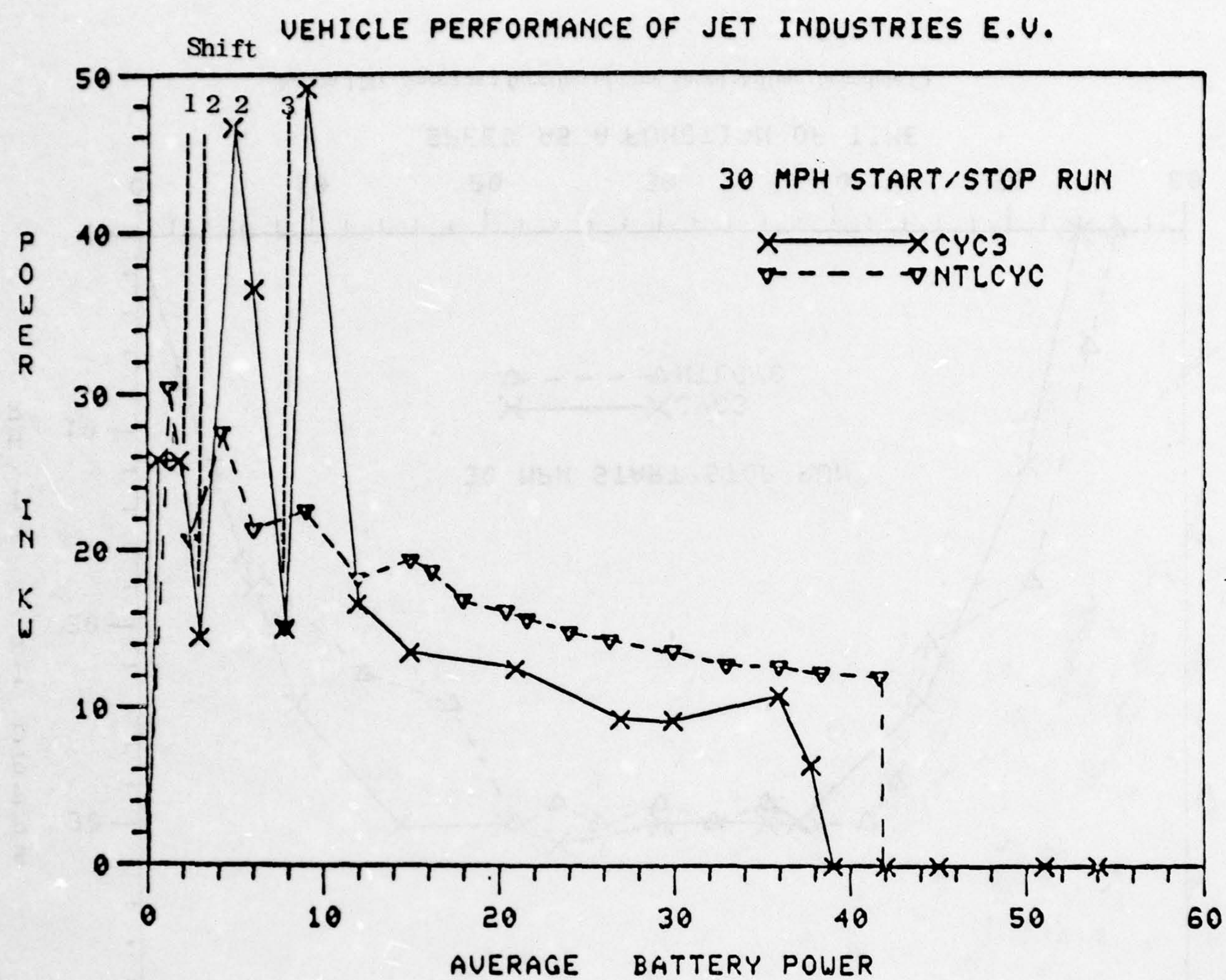

Figure 12C. Average battery power, speed shifting (Schedule C).

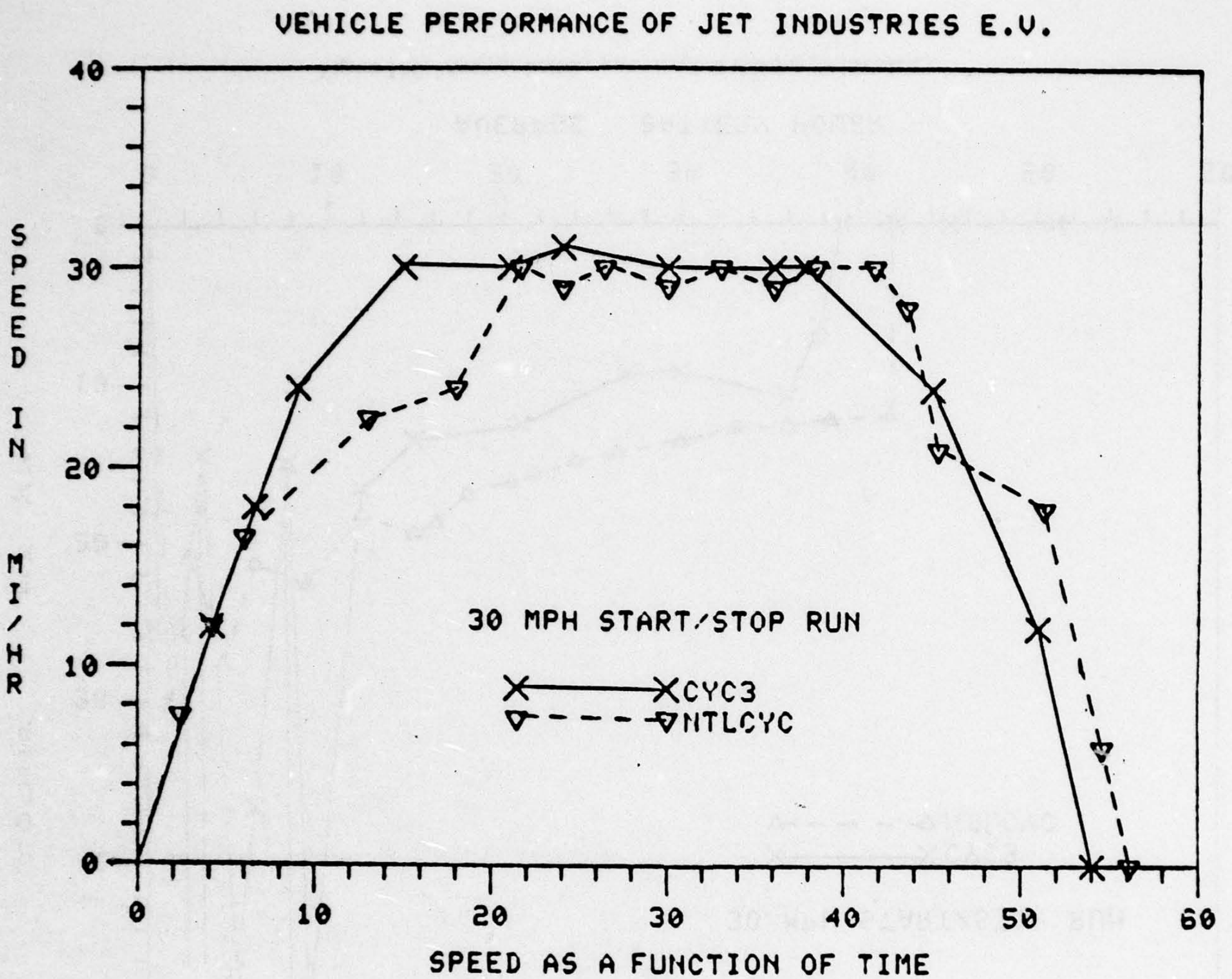

Figure 12D. Speed as a function of time, speed shifting (Schedule C).

Table 12. Driving Cycle Performance

Characteristic	Schedule B	Schedule C
Total Start/Stop Cycles	304	148
Distance Traveled During Test	103.2 km (64.1 mi)	89.1 km (55.5 mi)
Test Period	6.18 h	3.39 h
Kilowatt-Hours Used During Test	16.1 kWh	14.0 kWh
Average Watt-Hours Used Per Cycle	52.9 Wh	94.6 Wh
Average Cycle Duration	.0203 hr (73.2 s)	.0229 hr (82.5 s)
Average Time Battery is Loaded Per Cycle	.0107 hr (38.4 s)	.0113 hr (40.6 s)
Percent of Power Used for Acceleration to Crusing Speed	39%	52%

APPENDIX A

VEHICLE SUMMARY DATA SHEET

1. Vehicle Manufacturer: Name and Address

   Jet Industries Incorporated
   South Congress Avenue
   Austin, Texas
   (512) 443-4795

2. Vehicle Description

   Name: Electra-Van Model: 500-108
   Availability: 3 weeks Price: $7000.00

3. Vehicle Weight

   Curb Wt: 1180.4 Kg (2600 lb) Passengers Wt:
   Driver Wt: 68.1 Kg (150 lb) Payload Wt: 227 Kg (500 lb)
   Gross Wt: 1475.5 Kg (3250 lb)

4. Vehicle Size

   Wheelbase: 1.7 m (5.6 ft) Length: 3.3 m (10.8 ft) Width: 1.3 m (4.3 ft)
   Headroom: 0.88 (2.9 ft) Front; 0.91 (3.0 ft) Rear
   Legroom: 1.1 m (3.6 ft) Front; 1 m (3.3 ft) Rear

5. Auxiliaries & Options

   No. Lights: 10 Type and Function:
   a. Head Lamps
   b. Front Turn Signal Lamps
   c. Side Turn Signal Lamps
   d. Rear Combination Lamps
   e. License Plate Lamp
   f. Back-Up Lamp

   Windshield Wipers: Yes Windshield Washers: Yes
   Defroster: Yes Heater: Yes
   Radio: No Fuel Gage: Yes Ampmeter: No
   Tachometer: No Speedometer: Yes

Odometer: Yes Power Brakes: No Number of Mirrors: 3
Transmission Type: 4 Speed Manual Transmission Power Steering: Yes

6. Propulsion Batteries

Type: Lead-Acid Manufacturer: ESB, EV106
No. of Modules: 18 S/N:
No. Cells: 54 Battery Voltage: 108
AH Capacity: 132.5 Battery Size: 247.6 X 260 .3 X 177.8 mm^3
(9.7 X 10 .2 X 7 in^3)
Battery Wt: 531 Kg (117 lb) Battery Age: 6 months
Battery Rate: 106 min. 75 amps

7. Auxiliary Battery

Type: Lead Acid Manufacturer: Reliable
No. Cells: 6 Battery Voltage: 12V
AH Capacity: 60 Battery Size: 254 X 166 X 203 mm^3
(10 X 6.5 X 8 in^3)
Battery Rate: 20-hour rate Battery Wt: 13.6 Kg (30 lb)

8. Controller

Type: SCR Manufacturer: Cableform
Voltage Rating: 84 to 140 Volts Current Rating: 350 amperes
Size: 584.2 X 127 X 203 mm^3 Weight: 11.35 Kg (25 lb)
(23 X 5 X 8 in^3)

9. Propulsion Motor

Type: Traction Series Manufacturer: Baldor – St. Louis
Insulation Class: F Voltage Rating: 108 volts
Current Rating: 98 amperes HP Rating: 16
Size: 400 mm X 228.6 mm Dia. (15 in. X 9 in. Dia.)
Weight: 76.3 Kg (168 lb) Rated Speed: 5600 rpm
Max Speed: 6000 rpm

10. Body

Type: Cab-Steel Manufacturer: SUBARU
No. Doors: 5 Doors Type: Front: Hinged, Side: Sliding, Rear: Hatch Back,

No. Windows: 4 Windows   Type: Front: Regular, Rear: Sliding
No. Seats: 2+(2) Seats   Type: Bench
Cargo Volume: 1.65 m^3 (0.58 ft^3)   Cargo Dimensions: 1.6 X 1.1 X 0.94 m^3
(5.2 X 3.6 X 3.1 ft^3)

11. Chassis

Manufacturer: FUJI
Type Material: Steel   Modifications: None
Type Springs: Torsional   Type Shocks: Hydraulic
Axle Type Front: Swing Arm   Axle Type Rear: Swing Independent
Axle Manufacturer: FUJI
Drive Line ratio: 5.6:1
Type Brakes Front: Drum Hydraulic
Type Brakes Rear: Drum Hydraulic
Regenerative Brakes: No
Tire Type: Radial   Manufacturer: Pirelli
Size: 155SRZ 4-ply rated   Pressure: 40 lb/in^2 Front, 42 lb/in^2 Rear
Rolling Radius: 282.6 mm (11.13 in)

12. Battery Charger

Type: Const. Voltage, Const. Current   Manufacturer: Lester Corporation
On or Off Board: Off-Board   Input Voltage: 220V, 1 phase
Peak Current: 30A   Recharger Timer: 16 Hours
Automatic Turn Off: Yes

APPENDIX B

DESCRIPTION OF VEHICLE TEST TRACK

The test site used to conduct the tests described in this report is located at Aberdeen, Maryland. The track is owned and operated by the US Army. Three test sites were used.

1. **Gradeability Slopes.** Gradeability of vehicles is a basic characteristic usually given in design specifications of military vehicles. The Munson gradeability slopes (Figures B1 and B2) cover a range of 5 to 60 percent. They are used to determine optimum drive ratios and maximum attainable speeds on each slope, as well as brake-holding ability and adequacy of angles of approach and departure. With the test vehicle in both ascending and descending attitudes, functions such as lubrication, fuel flow, and carburetion are investigated. The effect of unbalance on turret traversing efforts and functioning of turret drive systems may also be studied on the slopes. The 5, 10, 15 and 20 percent slopes, approximately 14 feet wide, are paved with asphalt; the 30, 40, 45, 50 and 60 percent slopes, with concrete.

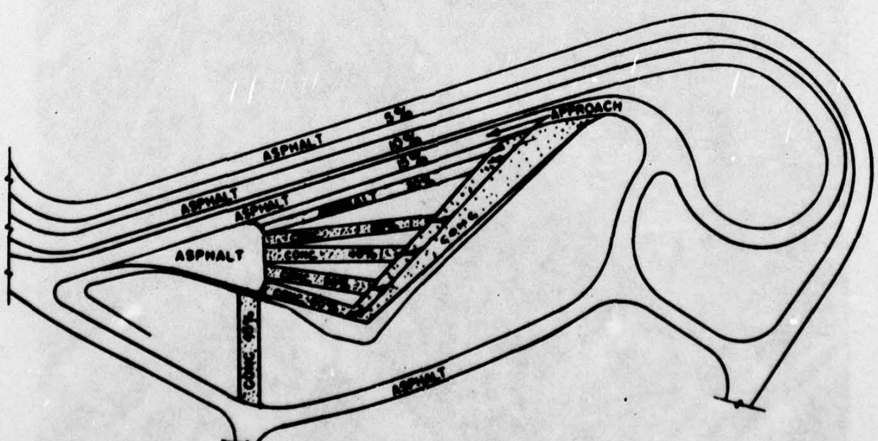

Figure B1. Plan View of Slopes.

Figure B2. Eight of the Standard Gradeability Slopes.

2. **Mile Loop.** The Mile Loop (Figure B3) was originally constructed in 1933 as a level concrete course of oval shape for continuous high speed operating tests of vehicles. Near the headquarters area of the post, the course consists essentially of two straight sections, each one-quarter-mile long, joined at each end by quarter-mile sections of regular curvature to form an oval of 1 mile total circumference.

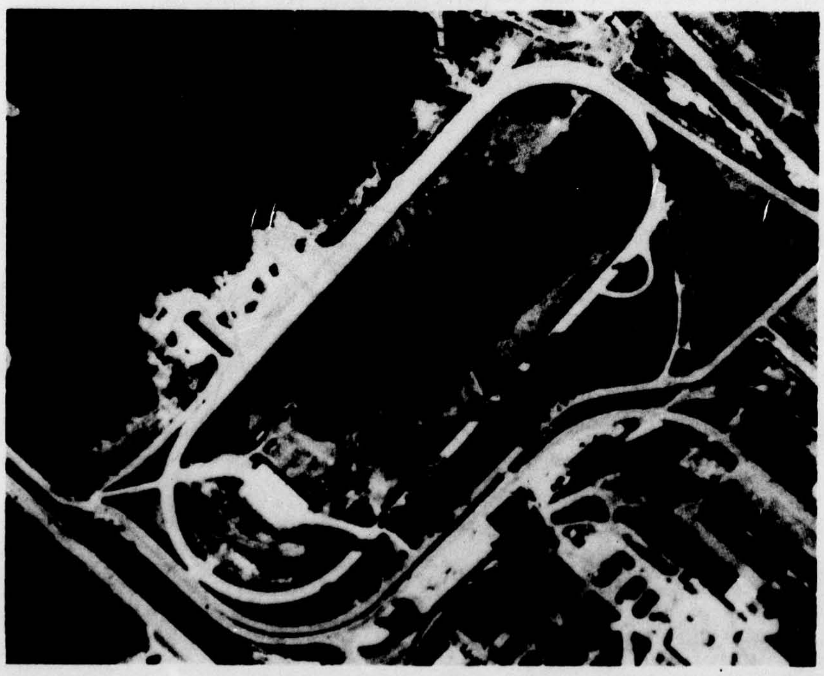

Figure B3. Aerial View of Mile Loop.

The course has been modified by covering and maintaining the surface with hot-mixed bituminous concrete and by the addition of a gravel surface parallel to and outside the oval. Several facilities also have been added in the area: a winch test facility, a "pothole-crosstie" course for forklift truck testing, and a 1-inch bump course for mobility testing of towed vehicles.

Winch Test Facility (Mile Loop). This winch facility has a restraining capability of 100,000 pounds and is used primarily as an anchor during winch endurance testing.

3. **Dynamometer Course.** The Dynamometer Course (Figure B4) is located in the Michaelsville section of the proving ground, 4 miles from the headquarters area. Constructed of reinforced concrete, with a hot-mixed bituminous surface, it is suitable for the operation of the heaviest tracklaying vehicles.

The course has a total gradient of less than 0.1 percent in its l-mile length, and turnarounds are provided at each end. It is used for closely controlled engineering tests such as drawbar pull and tractive resistance measurements, acceleration and braking tests, and fuel consumption measurements.

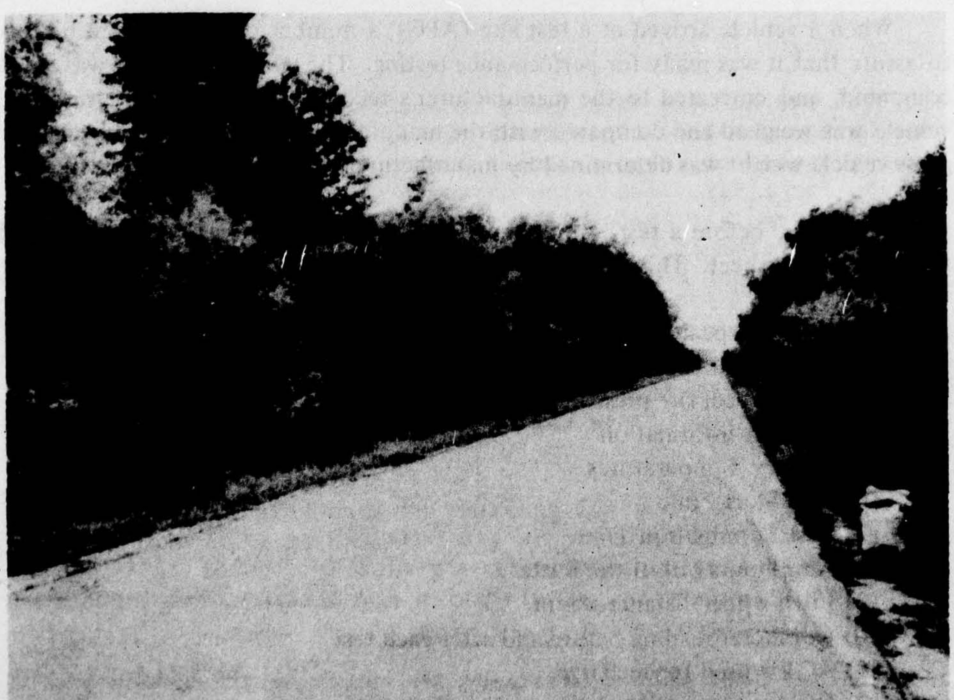

Figure B4. Dynamometer Course.

APPENDIX C

VEHICLE PREPARATION AND TEST PROCEDURE

When a vehicle was first received at Fort Belvoir, MERADCOM, a number of checks were made to assure that it was ready for performance tests. These checks were recorded on a vehicle preparation check sheet. The vehicle was examined for physical damage upon arrival. Before operating the vehicle, a complete visual check was made of the entire vehicle. The battery was charged and specific gravities were taken to determine if the batteries were equalized. If not, an equalizing charge was applied to the batteries. The integrity of the internal interconnections and the battery terminals was checked by drawing 300 amps or the vehicle manufacturer's maximum allowed current from the battery for 5 minutes; If the battery terminal or interconnection temperatures rose more than 60° C above ambient, the test was terminated, the terminals were cleaned, or the battery was replaced. The batteries were recharged, and a battery-capacity check was made. This test was made in accordance with the battery manufacturer's recommendations. To pass this test, the capacity had to be within 20% of manufacturer's published capacity at the published rate.

When a vehicle arrived at a test site (APG), a number of checks were performed to assure that it was ready for performance testing. The wheel alignment was checked, compared, and corrected to the manufacturer's recommended alignment values. The vehicle was weighed and compared with the manufacturer's specified curb weight. The gross vehicle weight was determined by manufacturer's rated pay load.

Each day, before a test, a number of pre-test checks were made and entered on the vehicle data sheet. This data included:

(1) Average specific gravity before and after test
(2) Tire Pressures
(3) Fifth wheel tire pressures
(4) Weather information
(5) Battery Temperatures
(6) Test Start Time
(7) Test Termination Time
(8) Amp-hours out of the Battery
(9) Fifth wheel distance count
(10) Odometer reading before and after each test
(11) AC kw used for recharge
(12) DC Amp-hours into battery on recharge

To prepare for a test, the specific gravities are first measured and recorded. The tire pressures are measured. The instrumentation is connected, and power from the instrumentation battery is applied. All instruments are turned on and warmed up, and all data channels are calibrated. The vehicle is towed to the starting point on the track. Weather data is recorded, odometer reading is taken. The test is started and is carried out in accordance with the DOE test and evaluation procedure. When the test is terminated, the test team makes all the proper checks and records all data on data test sheet for the day's test. After all checks are made, vehicle is towed back to the charge station placed on charge for next day's tests.

WEATHER DATA

Measurements of wind velocity and direction and ambient temperatures were taken at the beginning and at the end of each day's testing. The APG Airport weather station was used for all weather data.

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